Ohio Department of Natural Resources

Division of Soil and Water Resources

Technical Report

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A Functional Assessment of Stream Restoration in Ohio

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Abstract

Stream restoration has become a multi-million dollar industry while the science and techniques are still relatively immature. A wave of early projects are now established and lend themselves to systematic appraisals. To increase our understanding of stream restorations throughout Ohio, 51 stream restoration projects, comprising primarily physical reconfiguration, were characterized and several elements of their ecological integrity evaluated. The stream restoration projects assessed were constructed primarily to mitigate channel impacts from land development (94%). The lengths of individual projects were limited (median 1117 ft). The streams affected tended to be very small headwaters (median drainage area 224 ac).They also tended to be low energy (median stream power, 14 $lb_f/(s \cdot ft)$ at 2 yr peak discharge), with some very low energy more naturally associated with wetlands (25% < 5 $lb_f/(s \cdot ft)$ at 2 yr peak discharge). A multi perspective evaluation of ecological integrity emphasized physical characteristics (morphology, hydraulic process, vegetation, soil and habitat) and their deviation from natural condition. The most striking deficiency in morphology was the lack of connectivity with a floodplain. Relative to natural conditions, floodplains were most often both narrow and high. Performance standards were evaluated based on their correlation with modeled floodplain connectivity. In-stream structures were almost all riffles but indeterminately constructed for habitat or grade control. The riffles were largely stable. However, they were often filled with fines and colonized by wetland vegetation. Soil investigations revealed soil quality of many sites similar to reference soils but a similar number of sites were considerably worse, dominated by subsoil with poor consistence and low organic matter, permeability or root density. Predicting the quality of soil characteristics (R^2=0.69, P<<0.001) was best achieved by weighing the amount of in-situ and depositional A horizon against the amount of in-situ and constructed C horizon. The headwater habitat evaluation index (HHEI) scores showed virtually no correlation with other characteristics of ecological integrity. The only significant correlation was a positive correlation with stream power. The success of the observed stream restoration projects, as measured by several aspects of physical condition, varied widely despite meeting required permit performance criteria. The results of this study demonstrate a need for physical standards for restoration projects that physically reconfigure streams.

Acknowledgements

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Introduction

The physical alteration of stream channels has been taking place in Ohio since the mid-1800s. Tens of thousands of miles of streams have been channelized (Pavelis 1987). This monumental effort was undertaken primarily to improve the use of the land through improved drainage or reduced flooding (Keller 1976, Brookes 1988, ODNR 2008 and ODNR 2009). Only recently has ecological integrity become a common goal for channel work. While streams continue to be modified for drainage and flood control, there is now the added expectation for many of these projects to minimize ecological impacts. In addition, a growing number of channel modification projects now are undertaken for the sole purpose of improving ecological condition (Shields et al 2003 and Bernhardt et al 2005).

No one term precisely encompasses the projects assessed in this report, so we will imperfectly refer to them all as restoration. What constitutes ***stream restoration*** has been debated at length (NRC 1992 and Shields et al 2003). Noting that restoring pre-settlement conditions is rarely obtainable, restoration has been proposed to mean restoring the biota and ecological processes and services (Shields et al 2003, 33 CFR 332.2). This partial restoration has alternatively been described with terms such as renovation and rehabilitation. Either way the idea implied is to improve the existing condition, which is not necessarily the case. For example, where land development impacts a quality stream, the goal is to minimize ecological impacts. Most projects have been constructed for reasons other than ecological improvement. By restoration, we mean only that, within site constraints, one of the project goals was to maximize ecological condition.

Typically, stream restoration projects have occurred for ***mitigation***, defined by Shields et al (2003), as "an activity to compensate for or alleviate environmental damage. Mitigation may occur at the damaged site or elsewhere. It may also involve site restoration to an acceptable condition, but not necessarily to a natural condition". Not included in this report are projects that provide stream preservation or stream bank stabilization for infrastructure protection which are sometimes confusingly lumped together with restoration.

Ecological restoration may at times consist of manipulation of the biota including planting trees, reintroduction of species or control of invasive species. However, for the purposes of this study, stream restoration projects are limited to those that involve ***reconfiguration*** with a substantial change in channel form.

In spite of having no concise definition, the types of projects reviewed in this report demonstrate an initial attempt at implementing a new norm for the physical alteration of stream channels. Enough projects have been constructed and are becoming established to allow for meaningful evaluation. Learning from these projects was ***the goal of this assessment***, specifically better understanding which techniques are most appropriate for assessment, evaluation and measuring success, and identifying elements of standards and guidelines that will lead more efficiently to successful projects. For stream reconfiguration projects, undertaken at least in part to benefit ecological integrity, this report will:

- describe the characteristics and types of streams being restored,
- evaluate restoration success based on an array of ecological functions,
- explore methods understood to be integral with the ecological function, specifically elements of physical condition influenced by reconfiguration projects that may serve as practical indicators of less tangible ecological functions.

Background

Stream Restoration Monitoring and Assessment

Although the terms stream mitigation, restoration, renovation, reclamation and rehabilitation have been used throughout the scientific literature for several decades; the science is still relatively immature (Tompkins and Kondolf 2007). Early on, Kondolf (1996) encouraged systematic studies to evaluate the success of stream mitigation projects attempting to restore ecological function. The lack of pre-project and post-project multi-disciplinary data was seen as a weakness in the scientific community's ability to collectively learn about each project's effectiveness. Kondolf recommended monitoring a broad array of stream characteristics to accumulate knowledge on successes and failures.

A database of 1,345 stream restorations constructed between 1970 and 2004 in the upper Midwest (Michigan, Ohio and Wisconsin), was compiled by Alexander and Allan (2006) as part of the National River Restoration Science Synthesis project to evaluate the effectiveness of commonly used stream restoration practices. Alexander and Allan emphasized the need for more detailed and standardized evaluation. The monitoring results that did exist were generally discouraging. Fewer than half of the 1,345 regionally completed projects evaluated by Alexander and Allan (2007) were described as ecologically successful. According to Alexander (2005) in her study of Michigan, Wisconsin and Ohio streams, the majority of the restoration projects were not sustainable and chemical parameters showed no change after restoration indicating that the stream's assimilative capacity had not increased. Rather than seeing improved watershed scale results, Alexander and Allan (2006) observed a trend toward increasing project costs and decreasing project lengths over time, indicating more money was being spent on smaller and more expensive projects. They also noted an increasing tendency to refer to channel stabilization projects as restorations. According to the National River Restoration Science Synthesis project, many projects were implemented to address the symptoms of an environmental concern without first understanding the larger scale processes underlying the observed environmental degradation (Tompkins and Kondolf 2007).

Two notable methods have been proposed specifically for ecological assessment of stream restoration. The first is the post project appraisal (PPA) protocol described by Downs and Kondolf (2002) which was an exhaustive list of physical assessments with streamflow data; conveyance data; channel roughness; channel cross sections; longitudinal profile; channel bed material; aquatic habitat mapping; mapping emergent, riparian and floodplain vegetation; floodplain deposition samples; and comparisons of historical aerial photos. Another assessment method proposed was more a list of guiding principles. Palmer et al (2005) suggested restoration: 1) be based on an image of a dynamic healthy river; 2) measurably improve ecological condition; 3) be self-sustaining and resilient to external perturbations; 4) cause no lasting harm; and 5) have pre and post-assessments completed and publicly available. These two very different restoration assessment methods are ecologically comprehensive. However, neither provides much specific guidance or definitive criteria for stream restoration regulation or design. Well-founded stream restoration tools and assessment methods are not yet broadly established.

A third method is specifically a tool for the review of stream restoration proposals called RiverRAT for River Restoration Assessment Tool. It was developed by NOAA Fisheries and US Fish and Wildlife with an emphasis on west coast salmonid stream restorations. It starts with 16 questions regarding problem identification, the technical basis of the design and adequacy of assessment measurements. It goes on through links to a companion document, "Science Base and Tools for Evaluating Stream Engineering, Management and Restoration Proposals" to provide an in-depth resource suitable for large stream restoration challenges.

Ecological Integrity

Ohio's stream mitigation/restoration programs have a sound conceptual foundation based on ecological integrity, defined by Karr and Dudley (1981) as the ability of a system to maintain and repair itself. Smith et al (1995) explained ecological integrity as the integration of nested ecological functions composed of a hierarchy of the all things a system does, starting with the individual processes such as nitrogen removal, flood control or support for a specific biotic community as simple functions nested in broader processes all the way to the most complex, ecological integrity, which is the maintenance of all the integrated functions (Figure 1). ***This conceptual framework connects broad stream functions to measurable stream characteristics.*** The denitrification process, for example, necessarily entails denitrifying bacteria and organic matter in anoxic conditions. Peak flow attenuation by the process of flood routing is determined by measurable floodplain form and quantifiable channel and floodplain roughness. Vegetation communities require light and soil with quantifiable characteristics.

Some components of ecological integrity are influenced by stream projects more than others. In this assessment, an attempt was made to evaluate component variables most sensitive to the physical modifications of stream reconfiguration.

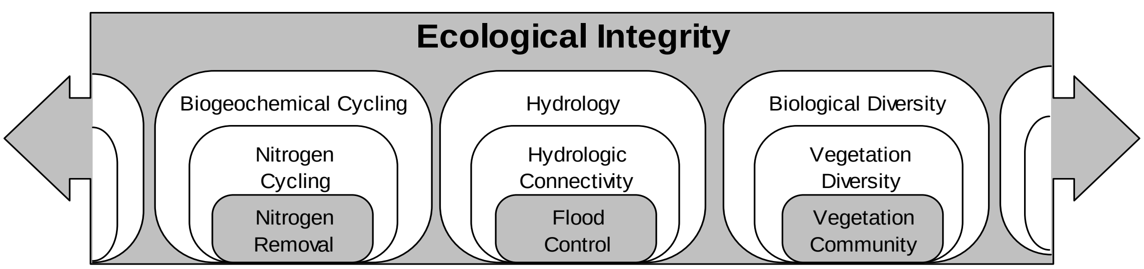

Figure 1 Ecological integrity is the integration of a hierarchy of many simpler functions down to individual ecological services (adapted from Fennessy, 2007 and Smith 1995). The simpler the function, the easier it is to describe by quantifiable structure and process variables.

Monitoring and Assessment in Ohio

An advantage when conducting monitoring and assessment studies in Ohio is that Ohio EPA's Division of Surface Water has been a national leader in using biological indicators to assess overall stream ecological integrity. Ohio EPA has developed a widely used Index of Biotic

Integrity (IBI) tool for fish assessment, an Invertebrate Community Index (ICI) tool for macroinvertebrates, and the Qualitative Habitat Evaluation Index (QHEI) and Headwater Habitat Evaluation Index (HHEI) tools for habitat quality assessment.

Ohio EPA recently initiated a study of the effects of stream restoration on fish and macroinvertebrate communities. Two years of pre-restoration data have now been collected (Ohio EPA 2009b and 2010a). Post construction studies by Ohio EPA will document the effectiveness of the biological recovery. These Ohio EPA biotic studies are specifically on Clean Water Act Section 319 funded stream restoration projects and do not include Clean Water Act Sections 401/404 permitted stream mitigation projects which tend to be relocated channels on developed sites rather than streams selected for restoration.

The 401/404 projects are monitored by the permittee, generally for stability, habitat and any special permit conditions. The monitoring period is a minimum of five years post construction with annual reports submitted to Ohio EPA and the US Army Corps of Engineers, both of which make site visits in the third and fifth year.

Compared to Ohio's established stream monitoring programs that assess the overall condition of Ohio's streams, monitoring more applicable to stream reconfiguration projects is still developing. Generally, assessment of physical integrity is now limited to aspects of habitat.

By comparison, considerable monitoring work that includes key physical attributes has been completed for Ohio wetlands. Ohio EPA generated four studies on the effectiveness of wetland restoration (Fennessy and Roehrs 1997, Porej 2003, Kettlewell 2005 and Micacchion et al 2010) and one report on the ecological effectiveness of wetland mitigation banks (Mack and Micacchion 2006). Ohio EPA developed the Ohio Rapid Assessment Method (ORAM) screening tool to determine the integrity of wetlands and the likelihood a comparable wetland could be created elsewhere. Ohio EPA also requires that the functions of mitigated wetlands be assessed and compared to natural wetlands using one of several OEPA vegetation, macroinvertebrate or amphibian wetland assessment tools (Micacchion 2004, Mack 2007 and Ohio EPA 2004a). Ohio EPA has used the results and conclusions of these wetland studies to better clarify the physical, chemical and biological requirements for future mitigated wetlands to be created under Section 401 requirements.

Physical Integrity

Water quality is a compilation of physical, chemical and biological integrity as defined by the Clean Water Act, the cornerstone protection for surface water quality. Since 1972 and the promulgation of the Federal Water Pollution Control Amendments, including The Clean Water Act, projects that physically changed streams by moving the centerline or placing fill required a permit and mitigation activities for those impacts.

Even though there is a lack of broadly established stream restoration assessment tools, there appears to be agreement that morphology, or the study of form, is a logical part of stream assessment. (This seems particularly apt for restoration involving stream reconfiguration.) Morphological assessments are based on direct measurements of the channel cross sectional dimension, longitudinal profile and meander pattern (Richards 1982). Stream form and process are inextricably coupled and thus an extension of direct measurement of stream form provides estimates of processes that take place at various flow rates. Vegetative roughness, velocity, shear stress and stream power are but a few of the process values routinely estimated as part of stream morphology assessment (Rosgen 1996).

Morphology assessment includes the entire area of the stream, not just the narrow strip typically wetted by daily flow but instead the entire width covered by high flows. Assessment of the floodplain is valuable because stream processes are largely episodic, during periods of high flow (Kondolf 2006). The flood pulse concept postulated by Junk, Bayley and Sparks (1989) described stream functions responsible for the productivity of river-floodplain systems as "batch processes" occurring at high flow. Palmer (1976) proposed the concept of a streamway to be inclusive of the portion of the valley that the dynamic meandering stream system occupies over time. The compound form that most natural channels exhibit with relatively broad floodplain and narrow channel allows streams to be self-maintaining through low flows and floods with a range of energy that crosses orders of magnitude (Leopold 1994). Thus, the forms that streams take at all flow rates are key to the evaluation of stream morphology.

A standard technique used in stream morphology is scaling proportional to the channel itself. The bankfull channel is consistently associated with those intermediate discharge rates that are both powerful enough and occur frequently enough to be most influential in the channel forming processes (Dunne and Leopold 1978). The bankfull channel dimensions commonly serve to normalize measured values and allow comparison of the characteristics of different size streams. For instance, floodplains can be described in terms of the number of times wider than the bankfull channel width. A floodplain 20 times wider than its bankfull channel is extensive whether it is a little headwater stream or a major river. Similarly, flood stages are expressed in multiples of the bankfull channel depth. For example, the width of flow at the stage two times the maximum bankfull channel depth defines the often-used term floodprone width (Rosgen 1994).

In addition to a stream's form and processes, another physical aspect is the material of which it is composed, its subsurface lithology. Streams do not simply flow over an impermeable two-dimensional surface, but flow through banks, beds and floodplains laterally and vertically (Figure 2). Ground water and shallow hyporheic water flow through channel bed material and riparian soils. Van der Putten (2004) described the ecological services provided by natural floodplain soils including retention of nitrogen in biomass, physical stabilization, interception of runoff, moisture retention, evapo-transpiration and carbon sequestration. For these, he described the necessity of soil supporting soil organisms (bacteria, fungus, nematodes, protozoa, earthworms and isopods). The material composition of a streamway has an intricate role in its ecological functions and is certainly manipulated by restoration work.

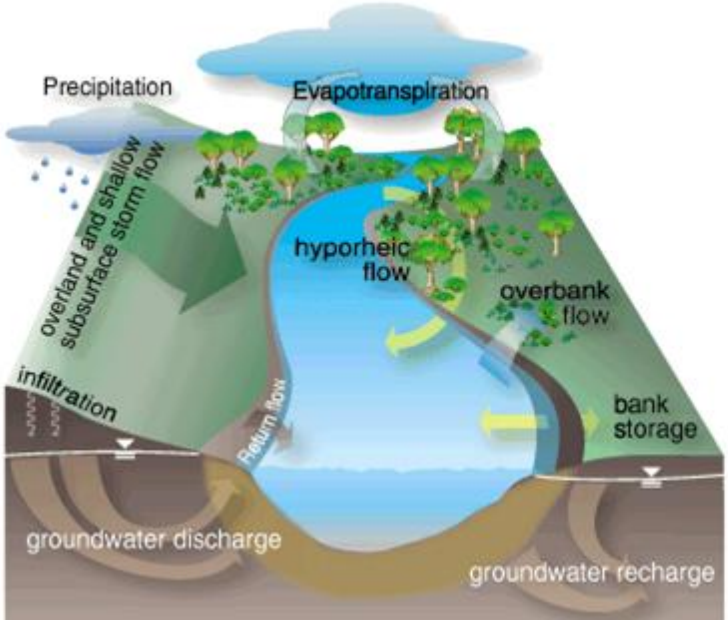

Figure 2 Water movement through streams emphasizing pathways between channel and riparian area. *(From the Committee on Riparian Zone Functioning and Strategies for Management, 2002. Reprinted with permission from the National Academies Press, Copyright 2002. National Academy of Science. Riparian Areas; Functions and Strategies for Management).*

Headwater stream channels have been lowered over a large portion of Ohio (Figure 3), virtually without exception in low gradient landscapes, to facilitate drainage. Soil stratigraphy is of particular concern in riparian areas where channelization occurred, because deeper strata tend to be less conducive to stream functions. For example, an earlier assessment by Division of Soil and Water Resources (DSWR) compared deeper strata to the upper layers of natural soil for 34 previously channelized streams in Ohio showing an average of 24% reduction in available water capacity, 35% reduction in permeability and a 73% reduction in organic matter, based on data compiled from Ohio soil survey physical properties (Mecklenburg 2008).

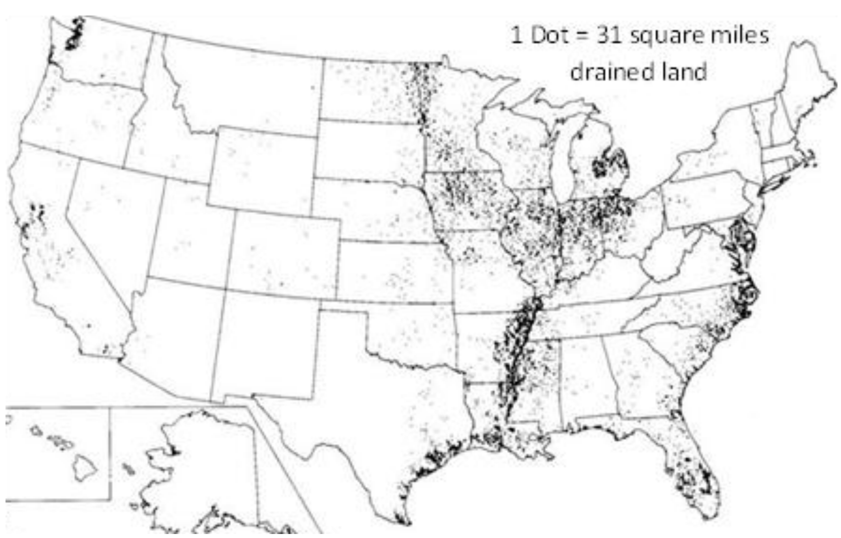

Figure 3 Distribution of drained lands in the United States (Pavelis 1987).

Methods

The physical condition of restored streams was investigated using multiple disciplines: morphology, vegetation, soils, and habitat. Characteristics were selected for their key functional roles in the nested scheme of ecological integrity.

Selection of Study Sites

For this study, 51 projects involving substantial channel modification were selected for monitoring from the total 518 permits issued in Ohio from 1996 to 2007. Permitted stream projects were those regulated by Ohio EPA Division of Surface Water's 401 Section, the United States Army Corps of Engineers' Nationwide permit 27 and 38, and Superfund cleanups (Figure 4).

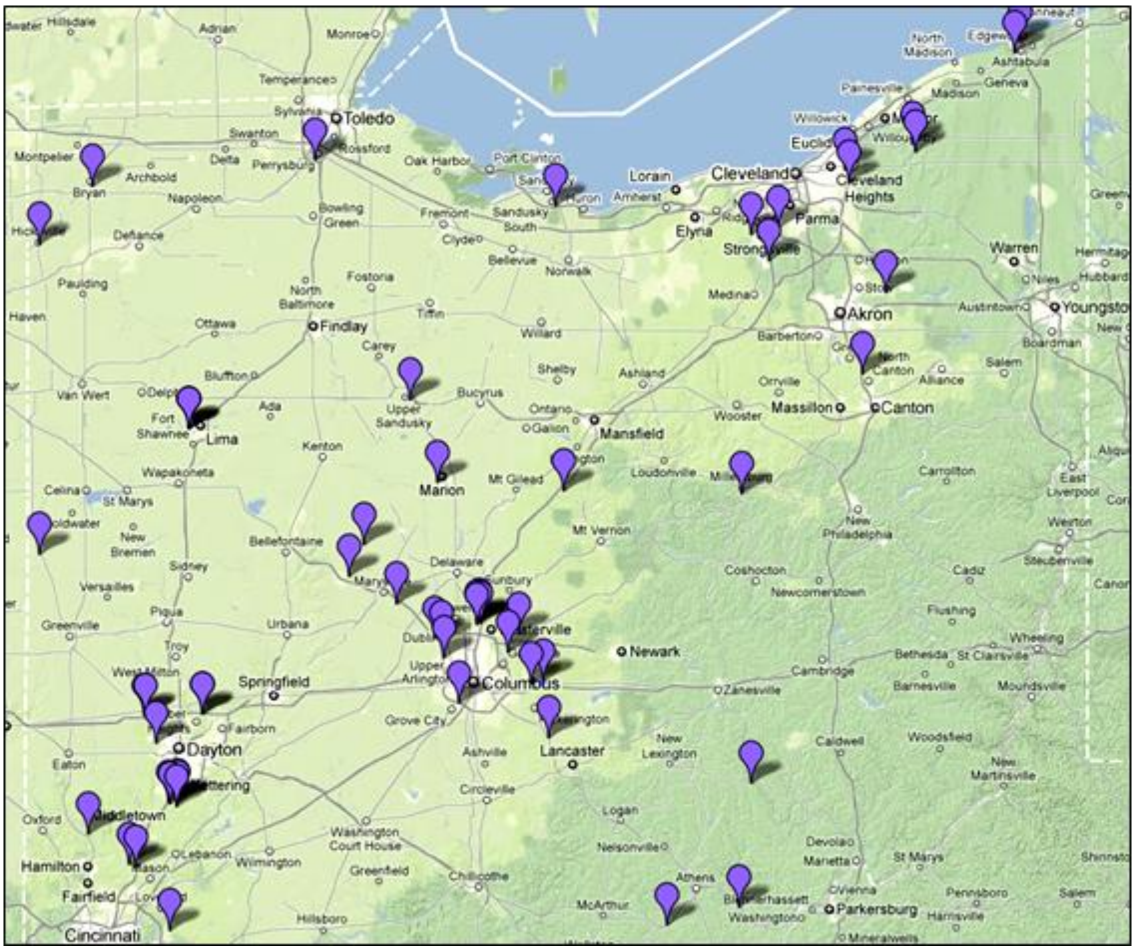

Figure 4 Assessed project site locations.
http://maps.google.com/maps/ms?ie=UTF8&hl=en&msa=0&msid=107960685558029914341.000452b1247b2a72059da&ll=40.375844,-82.650146&spn=4.017137,6.696167&t=p&z=8

The Ohio EPA's 401 Section provided DSWR a list of all projects that authorized stream impacts and required stream mitigation. Four hundred thirty six Section 401 projects were issued for stream impacts between 1996 and February 7, 2007. DSWR also obtained lists of 10 stream projects that were issued permits by the Army Corps of Engineers under Nationwide 38

(Cleanup of Hazardous and Toxic Waste) and 71 stream projects issued permits under Nationwide 27 (Aquatic Habitat Restoration, Establishment and Enhancement Activities). Superfund cleanups, by law, do not require either Clean Water Act 401 or 404 nationwide permits but are required to comply with substantive applicable, appropriate and relevant requirements (ARARs) from these types of permits. DSWR obtained information on one Superfund site (Fieldsbrook) that was comparable to the types of remediation efforts conducted in Nationwide 38 projects.

The combined list of 518 permitted projects included many that were predominantly bank armoring, riparian plantings, utility crossings and stream preservation, with little or no channel modification. The project descriptions were reviewed to identify mitigation that included substantial channel work. Recurring keywords such as restoration, relocation or remediation helped in the selection of projects with channel work. Permit administrators were also queried to help distinguish between projects with or without substantial channel work. Projects assessed were limited to those constructed from 1997 to 2006, limiting the variation in age and ensuring at least three years had passed post construction prior to the 2009 monitoring season. This review and evaluation resulted in a list of 51 permitted projects, one of which had two modified streams, resulting in 52 streams monitored and another project had three distinct designs in series, making the number of restored stream reaches 54.

Morphology

Channel dimension, pattern and profile were surveyed for each project. While conditions sometimes differed considerably within some sites, no attempt was made to describe the range of conditions. Rather, a reach was selected that appeared to be most representative of the project. If the stream generally appeared consistent, a section near the middle of the project was assessed.

The stream surveys largely followed the field technique described by Harrelson et al. (1994) using a laser level and survey tapes for the collection of stream channel measurements. Additionally a handheld GPS and Google Earth imagery supplemented channel pattern measurements. Measurements included bed and water surface elevations, changes in vegetation, top of bank, and indicators of channel formation (i.e., depositional surfaces such as benches, bars and breaks in the slope of the bank). Within each reach, two to four cross sections typically were surveyed as necessary to characterize the channel and the valley. For stream sites with uniform cross sections (e.g., Southgate Industrial Park) only one cross section was surveyed.

Surface bed material was assessed at riffles. An attempt was made to distinguish between mobile riffle surface material and material placed during construction. Pebble counts were performed for gravel and coarser material according to Ward and Trimble (2004) based on the technique by Wolman (1954). Silt and clay bed material was recorded based on visual and tactile observation. Embeddedness was noted as highly or moderately embedded as evidenced by silt and clay filling gravel or cobble interstices. Black staining on the buried portions of large particles and the absence of macroinvertebrates on those surfaces were used to indicate anoxic conditions.

Survey data were reduced and analyzed using a modified version of The Reference Reach Spreadsheet Version 4.3L of STREAM (Spreadsheet Tools for River Evaluation, Assessment and Monitoring) (Mecklenburg and Ward 2005)

Hydrology: Instantaneous peak discharges were estimated for the 2 to 100 yr recurrence interval (RI) events using USGS's Ohio urban and rural equations (Koltun and Whitehead 2001, and Koltun 2003). Peak discharges were then interpolated and extrapolated for an expanded doubling series, 0.2, 0.4, 0.8, …50, 100 yr RI, as described by Mecklenburg and Ward (2002) and (Powell et al 2006)

Hydraulics: The Reference Reach Spreadsheet was modified to analyze not just bankfull flow, but also the flow at a stage equal to the regionally predicted maximum bankfull depth and each of the 10 peak discharge rates of the recurrence interval series from 0.2 to 100 yrs. At each stage, only the cross sections appropriate for describing that stage were selected for analysis. For example, a riffle crossing over between two outside bends might be the best location for describing in-channel flows, but to describe flood flows a cross section perpendicular to the valley may be more suitable.

Manning's roughness coefficients were selected for three stages; low flow (0.2 yr RI), high flow (100 yr RI) and at bankfull (the flow stage associated with major breaks in the cross sectional geometry). Estimates of roughness were made iteratively to allow the effects of relative roughness and vegetation submergence to be accounted for in the determination. A spreadsheet macro was written to find the flow stage with the flow rate that matched the hydrologically predicted peak discharge for each recurrence interval. Roughness coefficients for these three stages were selected using Chow (1959) and Barnes (1967). Channel and floodplain roughness coefficients for peak discharges of recurrence intervals between the three stages were assigned values by interpolation.

Vegetation Assessments: Vegetation varied considerably from site to site and within individual sites. Several assessment methods recorded characteristics of vegetation. The density of vegetation was recorded on a range from dense and vigorous to sparse and separately by zone: channel bed, riffles, bankfull channel, near bank and floodplain. Root density, quantified during the soils investigation, is another measure of riparian vegetation. Manning's roughness coefficients further reflected the vegetation. Lastly, the basal area method was explored. This assessment technique, as defined by Bonham (1989), involves cutting and bundling the vegetation within a 1-meter square PVC quadrat, then measuring the circumference of the bundle for the total stem density using the linear diameter measure technique of Pearse (1935) and described by Bonham (1989). Vegetation assessments were done at randomly selected locations in both the channel and the floodplain for four sites.

Soil Investigation

Soil scientists from the Ohio DNR, Division of Soil and Water Resources applied the techniques and skills established for soil mapping and land capability analysis to assess riparian soil quality. This approach to the soil investigations was selected for the comprehensive view of soil health it provides.

Sampling locations within the projects site were selected to be representative of the active floodplain. The investigation went to a depth equivalent to the elevation of the adjacent streambed such that the soils described are those that interact most with the stream during periods of low flow as well as floods. At several sites, more than one investigation was performed to describe substantially different conditions. A corresponding reference condition investigation was performed for approximately half of the sites. This entailed the initial identification of potentially undisturbed riparian soil near the site was initially identified using remote imagery with the final location selected by the soil scientist in the field. No soil investigations were performed for four of the projects that were highly entrenched with no discernable floodplain. A total of 77 soil investigations were performed during the study.

Soil investigations involved excavation of pits by hand spade, followed by deeper excavation with a bucket auger. Soil characteristics of color, redoximorphic features, texture, organic matter, structure, consistence, and roots were recorded based on the methods of USDA NRCS (2002). The origin of each horizon was recorded as constructed (re-soiled) material, soil deposited or accumulated post construction, or natural material left in place although material may have been removed above it. Soil profile horizon thickness was recorded using nomenclature as established by the Soil Survey Staff (1998, 1999). A sample of the form can be seen in Figure 5. A more detailed description of soil investigation techniques is in Appendix A.

County:	Medina	***Land Use:***	use is a natural area	***Date:***	September 18,2008
Location:		***Vegetation:***	honey locust, weeds, grass	***Evaluator:***	Steve Prebonick
Regional Curve:	Mid Ohio	***Landform:***	floodplain		
Drainage Area:	0.42	***Position on Landform:***	flat	***Method***	
Watershed:		***Percent Slope:***	0.5	***Pit:***	X
Project Name:	Brunswick Town Center	***Test Hole #:***	B (south side of the drain)	***Auger:***	X
Site Name:	Site B	***Latitude / Longitude:***	N 41 14 07.6 W 81 48 27.1	***Probe:***	

Soil Profile			Saturation - Munsell Color			Soil Permeability											
	Depth (in)			Redoximorphic Features		Texture	Clay	Frags	OM	Structure			Consis-	Tyler		Effer-	
Horizon	Top	Bottom	Matrix	Consentrations	Deletions	Class	(%)	(%)	(%)	Grade	Size	Shape	tance	Rate	Roots	vesence	Origin
A	0	0.2	10YR 4/2			SiL	7	0	3	1	f	gr	Fr	0.6	M f&vf		D
2C	0.2	5	10YR 4/2			CL	31	7	2	0		m	Fi	0	C f&vf	es	C
3C1	5	20	10YR 5/4			CL	32	10	0.3	0		m	Fi	0		es	I
3C2	20	36	10YR 5/4	7.5YR 5/6		GR-L	23	25	0.3	0		m	Fr	0.5		e	I

Width of water in channel: 7 feet
Distance from center of channel: 30 feet
Relative elevation above water surface: 30 inches

Additional notes:
flooding area 50 to 60 feet wide ; A horizon is recently deposited flood plain sediments; 2C horizon is a mixture of topsoil and subsoil fill; 3C1 horizon is original parent material; 3C2 is original parent material

Figure 5 Example of Soil Data Sheet

Soil Profile - Soils are described in layers called horizons. Depth and characteristics of each horizon were recorded. Generally, there are three basic horizons, A, B, and C. The A horizon is normally the top layer of soil called topsoil. This layer has the largest accumulation of organic matter and is the most biologically active. The next deeper horizon is the subsoil or B horizon which is often divided into subhorizons with letters indicating conditions in which they formed. The C horizon is not actually soil but parent material, and has far less structure and organic matter, and more restricted root growth compared to the upper horizons. C horizons are usually far less permeable although occasionally layers of sand and gravel may actually make them more permeable.

Soil Texture is the percent sand, silt, and clay correlated to the USDA textural triangle for the textural class. It affects water holding capacity, water movement, and root growth. Soil texture was estimated in the field by hand, using the ribbon method as described by Thien (1979).

Soil Organic Matter accumulates from roots and when organic matter deposition exceeds decomposition, and strongly influences microbial and chemical activity, water movement and root growth. The percent of organic matter was estimated with visual-manual field methods using the Color Chart for Estimating Organic Matter in Mineral Soils in Illinois (University of Illinois Extension 1995).

Soil Structure was characterized by three variables - grade, size and type - according to the National Soil Survey Center, NRCS, USDA (Schoenberger 2002). Soil structure characterizes the tendency of a soil mass to break along distinct planes. Well-developed soil structure increases soil permeability and facilitates root growth. Soil structure can be lost in cut and fill operations and by compaction caused by construction activities. Once structure is destroyed, it typically takes a very long time to redevelop, especially in the lower horizons. When stream restoration projects are relocated into parent material (C horizon), it could take up to 1000 yrs for this material to develop into soil (Jenny 1994).

Soil Consistence describes soil resistance to deformation and strongly affects water movement, water holding capacity, and root growth. Visual-manual methods for field determinations take into account resistance to rupture, resistance to penetration, plasticity, and toughness (Soil Survey Division Staff 1951). The observations recorded are loose, very friable, friable, firm, and very firm. Topsoil with good tilth is typically very friable or friable. DSWR Soil Scientists set a numeric scale of consistence quality for use in calculating a single depth weighted average score for each profile. The scale values were 3 for both loose and very friable, 2.5 for friable, 0.5 for firm and 0 for very firm.

Soil Permeability is the rate of water movement through the soil profile. It is a complex product of various soil morphological characteristics and processes. The Tyler loading rate (Tyler 2001) was chosen as a practical indicator of soil permeability but also because of its established correlation with microbial activity (Tugel and Lewandowski 1999) and nutrient uptake rate (Doyle 2003). The Tyler loading rate was developed to assign hydraulic wastewater loading rates to soil based on combinations of soil texture, structure type, and structure grade. These soil characteristics are observed and recorded along with a rating from the Tyler Chart (Tyler 2001). While the loading rate values have units of gallons/day/ft^2, these units are not applicable to floodplain processes. Instead, the Tyler loading rate values are used as a unitless scale starting at zero indicating a restrictive soil horizon with water movement in such horizons very slow with restricted root growth. Horizons that are more permeable have higher values on the scale. For example, an undisturbed loam with excellent structure is assigned a value of 0.8. The high end of the scale is 1.6 for the least restrictive soil horizon, such as coarse sand with the most potential infiltration.

Root Density was estimated in the field according to the protocol defined by the National Soil Survey Center (Schoenberger 2002). For each soil horizon, roots were indicated as many, common, few, and very few. To calculate a single depth weighted average score for root density, a numeric scale corresponding to the root density designations was defined. DSWR soil scientists reviewed the National Soil Survey Center protocol, debated and reached consensus on a root density scale of 4, 3.5, 2.5 and 0 for the designations many to very few.

Soil Origin is the soil morphogenesis as related to the restoration project. Each soil horizon was categorized as an undisturbed natural in-situ layer (I), as placed during project construction (C), or as deposited post project construction (D). The designation was evident from the soils investigation.

Habitat Assessments

Two established rapid assessment stream habitat protocols were utilized, the Ohio Environmental Protection Agency's Primary Headwater Habitat Evaluation Index (HHEI) (Ohio EPA 2002) and the Qualitative Habitat Evaluation Index (QHEI) (Ohio EPA 2006). The Ohio EPA released a revised version of the HHEI manual in October of 2009, but none of the metrics or submetrics ranges changed from the original version and therefore did not affect the results. The HHEI assessment method evaluates three metrics: visual estimation of substrate type, maximum pool depth, and bankfull channel width. The QHEI evaluates 6 metrics (substrate, in-stream cover, channel morphology, bank erosion and riparian zone, pool/glide and riffle/run quality, and gradient) to determine if the channel has the physical potential to support warmwater habitat fish communities. Ohio EPA developed the evaluation tool for primary headwater streams because they recognized streams at this watershed scale generally did not have sufficient water flow or physical habitat features to support well-balanced reproducing communities of fish, although they did often support diverse communities of macroinvertebrates, amphibians and pioneering species of fish (Ohio EPA 2004b).

The HHEI was developed for streams with drainage areas less than 1 mi^2. The QHEI protocol was developed and calibrated for streams with drainages greater than 3.1 mi^2. Between 1 and 3.1 mi^2 both methods were used; Ohio EPA (Mishne 2009) recommends the most appropriate assessment tool be determined case by case, based on a stream's potential to support warmwater habitat fish and macroinvertebrate communities. Because so few steams were clearly in the range for QHEI, greater than 3.1 mi^2, the HHEI was performed at all sites. Both the HHEI and QHEI assessments were performed by an Ohio EPA Certified Credible Data Level 3 staff member.

Results and Discussion

The following section is generally organized by the independent driving variables given for each site, followed by characteristics directly influenced by the design and construction, and then the resulting habitat.

Inherent Site Characteristics

The first five characteristics discussed: site location, project length, stream size, slope and stream energy are largely given features of the watershed or the property involved and not a function of stream design.

Site Locations tended to be around the more densely populated areas of Ohio, not surprising since most permitted projects are associated with land development: commercial (20), roads (10), residential (7), schools and churches (5), industrial (2), utilities (3) toxic cleanup (2), and agriculture (2). Although only two projects were constructed for agricultural purposes, eight were a functional part of an agriculture drainage system. Only three of these projects were specifically selected for physical restoration or mitigation of channel impacts elsewhere.

Project Length, or more specifically the affected channel length, had a median value of 1,117 ft, with the inter-quartile range (middle 50%) of the streams from 703 to 1943 ft (Figure 6). All but one stream were less than 3,400 ft. The longest stream, at 11,780 ft (2.2 mi), was Fieldsbrook, a Superfund Hazardous Waste Cleanup.

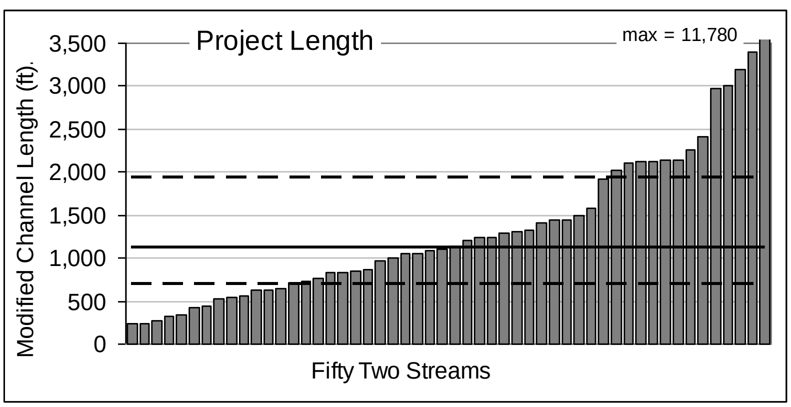

Figure 6 Reconfigured stream channel length. The median is shown as a solid line and the inter-quartile range as dashed lines.

Most streams, 32 of 52, were within plus or minus 10% of the length required by their 401 permit (Figure 7). Seven streams were more than 10% longer than required, while 13 were more than 10% shorter than required.

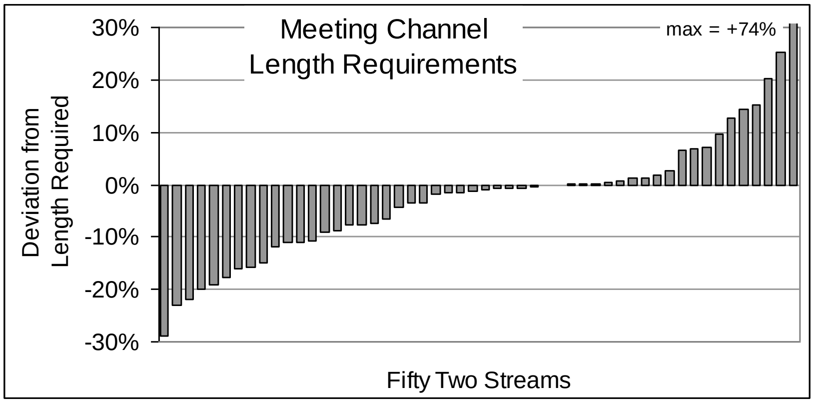

Figure 7 Reconfigured channel length measured relative to the 401 permit required channel length.

Stream Size is described in terms of the total drainage area contributing runoff to the project reach. The median drainage area size was 0.35 mi^2 (224 ac) and the inter-quartile range was 0.16 mi^2 (102 ac) to 0.59 mi^2 (378 ac). The entire range of stream drainage areas was from the smallest 0.012 mi^2 (7.7 ac at Meadowlands in Chardon, Geauga County) to 12.8 mi^2 (8,192 ac at Owl Creek Farm, Knox County) (Figure 8). Eighty five percent of the streams assessed were primary headwater habitat, i.e., less than 1 mi^2, as defined by the Ohio Environmental Protection Agency (Ohio EPA 2002).

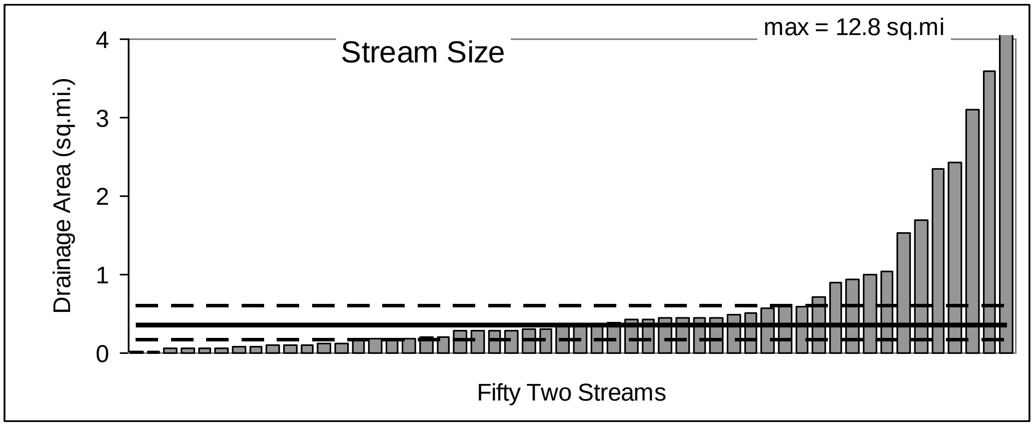

Figure 8 Watershed size contributing to project streams. The horizontal line shows the median value of 0.35 mi^2. The inter-quartile range from 0.59 to 0.16 mi^2, is shown by dashed lines.

Channel Slope is the local channel slope calculated from the longitudinal channel profiles. The median slope was 0.36%. The inter-quartile range of the streams was from 0.2 to 0.7%. Only two streams were “steep”, above 2%, one of which was 4%, the Ohio Department of Transportation’s (ODOT) State Route 37 project in Morgan County. The Rosgen Classification of Natural Streams established a 2% slope threshold between flatter riffle-pool channels associated with floodplains and steeper channels characterized by rapids and confined flood flows (Rosgen 1994). Ohio EPA’s Headwater Evaluation Index (HHEI) describes slopes less than 0.5% as flat. Thirty-four out of the 52 streams (65%) had slopes that were less than 0.5 % (Figure 9).

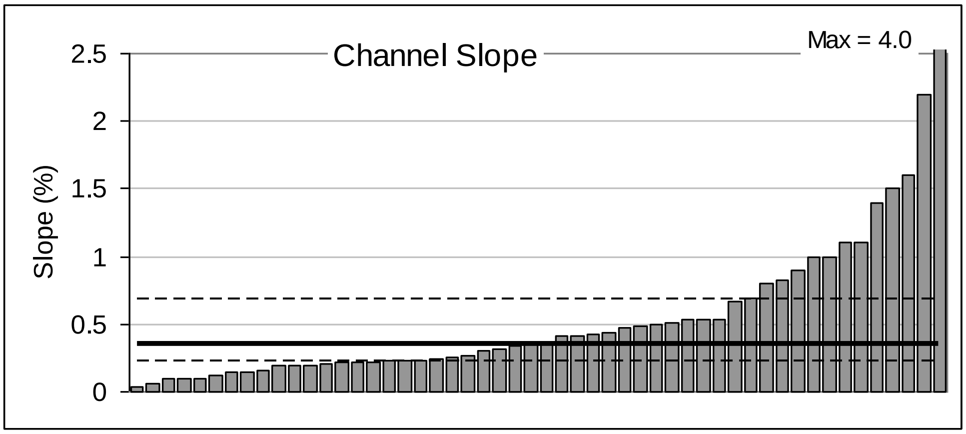

Figure 9 Local channel slope for the 52 streams assessed. The solid black line represents the median of the projects and the inter-quartile range is shown by dashed lines.

Energy – In addition to describing streams by their gradient and their size separately, the product of these two variables describes the stream energy, i.e., the work flowing water does in maintaining channel form and driving stream processes. Streams with similar energy have many similar characteristics. Large streams on flat slopes have similarities with smaller steeper streams. Energy is commonly described by the term "stream power," the amount of energy per unit time (power) per unit stream length (Equation 1). The 2 yr discharge rate was selected for use in this equation because it is estimated by most runoff methods and closest to the channel-forming flows of most streams. Because the 2 yr discharge rate is independent of channel size, it provides a useful benchmark for comparing the energy driving a stream system. Stream power based on bankfull discharge introduces additional site variables that will be explored later in this report.

$$\Omega = 62.4 \times Q \times S \qquad \text{(Eq. 1)}$$

Stream Power where: Ω = stream power ($lb_f/(s\cdot ft)$) Q = discharge rate (ft^3/s), and S=slope (ft/ft).

Stream power of the 2-yr recurrence interval (RI) peak discharge was evaluated for all the streams (Figure 10). The median value was 14 $lb_f/(s\cdot ft)$ and the inter-quartile range of the streams was 5 to 26 $lb_f/(s\cdot ft)$. In contrast, the named streams in Ohio from the Gazetteer of Ohio Streams (ODNR 2001) have an estimated median value of 67 $lb_f/(s\cdot ft)$, five times larger than the median value of the assessed streams. Three quarters of the assessed sites have energy levels below the lowest 20th percentile of named Ohio streams.

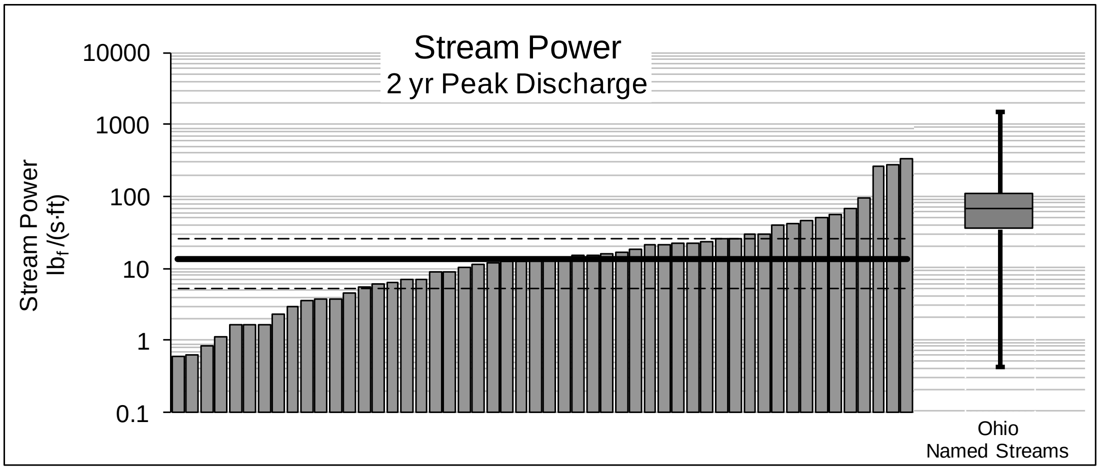

Figure 10 Stream energy presented as stream power of the 2-yr peak discharge. The solid line shows the median value, 14 $lb_f/(s{\cdot}ft)$, and the inter-quartile range, 5 to 26 $lb_f/(s{\cdot}ft)$, is shown by the dashed lines. For reference, the box and whisker quartile plot is from 3285 values developed from the Gazetteer of Ohio Streams and USGS peak discharge equations.

Morphology

Channel Size is often discussed in terms of the recurrence interval (RI) of its bankfull flow, i.e., channel flowing full without overtopping its banks. Leopold (1997) explained, "nearly all stream channels, whether large or small, will contain without overflow approximately that discharge that occurs about once a year". The median bankfull flow recurrence interval (RI) estimated for the 54 assessed reaches was 0.36 yrs. The inter-quartile range of the channels was from 0.20 to 0.52 yr RI and the minimum and maximum were 0.1 to 2.1 yrs (Figure 11).

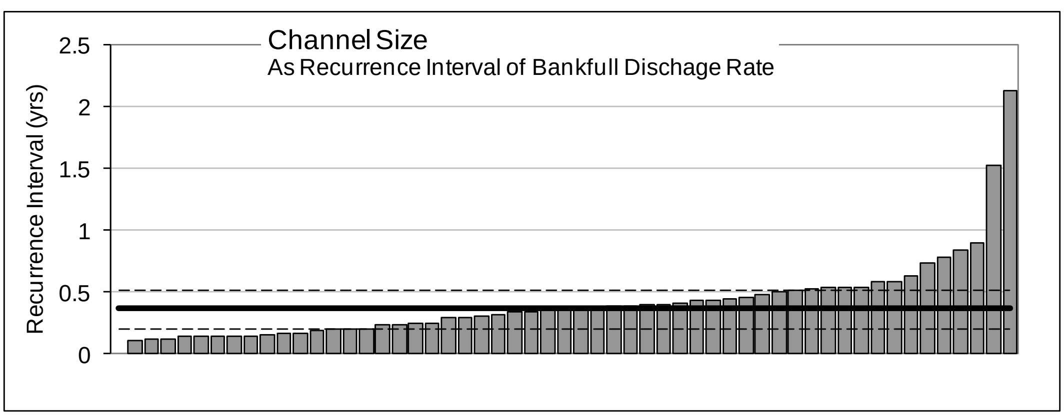

Figure 11 Channel size shown as the recurrence interval (RI) of bankfull flow rate. The median is 0.36 yrs, shown by the horizontal line. The inter-quartile range was 0.20 to 0.52 yrs, shown by the dashed lines.

Naturally formed channels typically are larger than most of the channels in the reaches assessed. Typically, streams form such that they flow bankfull at a recurrence interval near 0.8 yr based on a partial duration series, which is generally equivalent to the often-quoted 1.3 yr bankfull RI based on an annual peak series (Langbein 1949). Sherwood and Huitger (2005) found a median of 1.38 yr RI for bankfull discharges for their 40 gaged study sites in Ohio. However, some less often referenced evidence suggests that bankfull discharge may be much more frequent in certain conditions: at the head of the drainage basin (Richards 1982), in wetland streams (Jurmu and Andrle 1997) and in channels self-formed in over-wide drainage ditches (Landwehr and Rhoads 2003).

The methods used to describe bankfull events that happen many times a year are problematic. Recurrence intervals are traditionally based on the single largest discharge rate for each year of the period of record, called the annual peak series. This series is readily available and satisfactorily describes big, rare events. On the other hand, a partial duration series consists of all peaks above a specified threshold. The two are related as shown by Equation 2 adapted here from Langbein (1949). They correspond well for events greater than the 2 yr RI. However, a partial duration series is more descriptive of events near the 1 yr RI and certainly much better for describing events occurring many times a year. A drawback of using partial duration series is data are not as readily available as annual peak data. A third approach describes frequent events as a fraction or percentage of the 2-yr peak discharge (Equation 3).

$$RI_P = \frac{-1}{\ln\left(1 - {}^{1}/_{RI_A}\right)} \qquad \text{(Eq. 2)}$$

Partial duration series RI as related to annual peak series RI where: RI_P = recurrence interval based on partial duration series, and RI_A = recurrence interval based on annual peak series.

$$Channel\ Size = \frac{Q_{BkF}}{Q_{2yr}} \times 100 \qquad \text{(Eq. 3)}$$

Channel size represented as it's bankfull flow capacity relative to the 2 yr RI peak discharge where: Q_{BkF} = Bankfull discharge and Q_{2yr} = 2 yr annual peak discharge based on annual peak discharge series.

The bankfull flow rates of the channels assessed had a median 25% of the estimated 2 yr peak discharge, the inter-quartile range of the channels was from 10% to 50% of the 2 yr peak discharge, and the minimum and maximum were 2% and 110% of the 2 yr peak discharge (Figure 12). The commonly referenced 1.3 yr RI peak discharge is often around 70% of the 2 yr peak discharge. But then again Landwehr and Rhoads (2003) reported stable channels that formed in the agricultural landscape of central Illinois were 5% to 8% of the 2-yr peak, similar to the lower quartile of the channels assessed for this report.

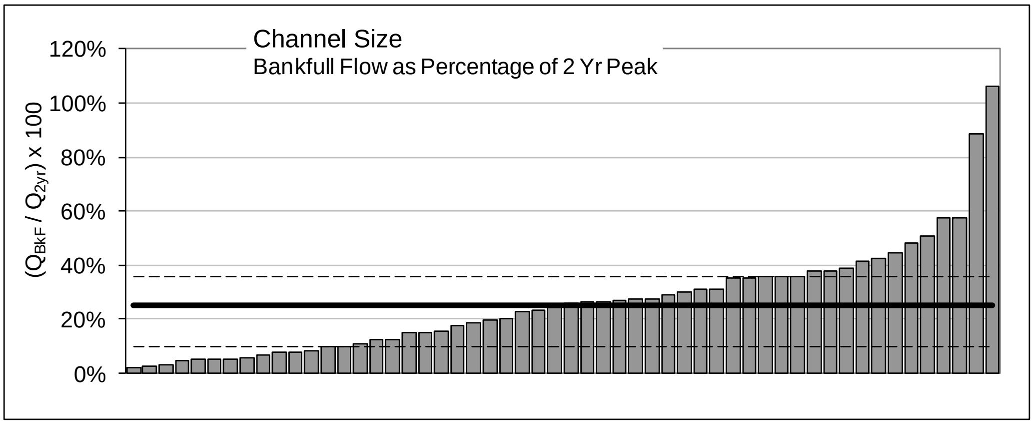

Figure 12 Bankfull discharge as a percentage of the 2 yr RI peak discharge.

Floodplain Connectivity is a general concept in ecology regarding the interaction between the channel and floodplain (Kondolf 2006). It is governed predominantly by the relative elevation and extent of the floodplain. Three methods of quantifying floodplain connectivity were used: 1) entrenchment ratio, 2) weighted floodplain width and 3) modeled floodplain area exposed to inundation over time. Reference floodplain width and flood stage are presented for comparison with all three methods.

Floodplain dimensions are often expressed in terms of ratios of bankfull channel dimensions. For example, lateral width of a floodplain may be described in terms of the equivalent number of bankfull channel widths, and flood stages described in terms of a number of bankfull channel depths. Because of the typically consistent size of bankfull channels relative to their drainage areas, this approach usually works well. However, assuming consistent bankfull channel size relationships does not appear valid for many of the streams involved in mitigation in Ohio.

Because streams are largely scalable, their proportions are often described as functions of the size of their contributing drainage area. A regional curve is a generalized relationship between drainage area and channel dimensions typical of a hydro-physiographic region. Regional curves can serve as a basis for defining the floodplain dimensions. They are possibly even more appropriate than dimensions defined as multiples of the bankfull channel dimensions.

Floodprone Width - While natural floodplains vary considerably in lateral extent, on average floods of large rivers are proportionately wider than floods of small streams. The scalable nature of floodplains makes it possible to define as point-of-reference a typical natural floodplain width proportionate with various channel dimensions or drainage area.

Equation 4 defines a target floodprone width as a function of drainage area. The target floodprone width was developed based on several natural characteristics: entrenchment ratios, the lateral extent of meander patterns, bed load sediment transport, and measured streams in Ohio (Ward et al 2002) and updated by ODNR (2006). The target floodprone width applies to natural streams in Ohio with channel slopes less than 2% and is fully described in the "*Rainwater and Land Development"* manual (ODNR 2006).

$$Target_{FPW} = 12.6(DA)^{0.38} \quad \text{(Eq. 4)}$$

Target floodprone width from drainage area where: $Target_{FPW}$ = target floodprone width (ft), and DA = drainage area (ac).

Flood Stage - Perhaps the most common measure of floodplain connectivity is the entrenchment ratio defined in part by the bankfull channel depth. Specifically, floodprone width is defined at a stage twice the channel depth. The stage at 2 times the maximum channel depth was selected, as is described by Rosgen, to be in a range around a 50 yr recurrence interval for the various channel types. The rationale for defining this stage is based on the correlation with flood events of this magnitude (Rosgen 1994). However, that correlation was not observed in the streams assessed for this report. The 50 yr RI stage of the observed streams averaged more than 3 times the depth of the existing channels, had a standard deviation of 1.1 and was as high as 6.7 times the existing channel depth (Figure 13). For the observed channels, the flow stages defined by 2 times the measured channel depth ranged from routine flows to flows so large that they would virtually never occur.

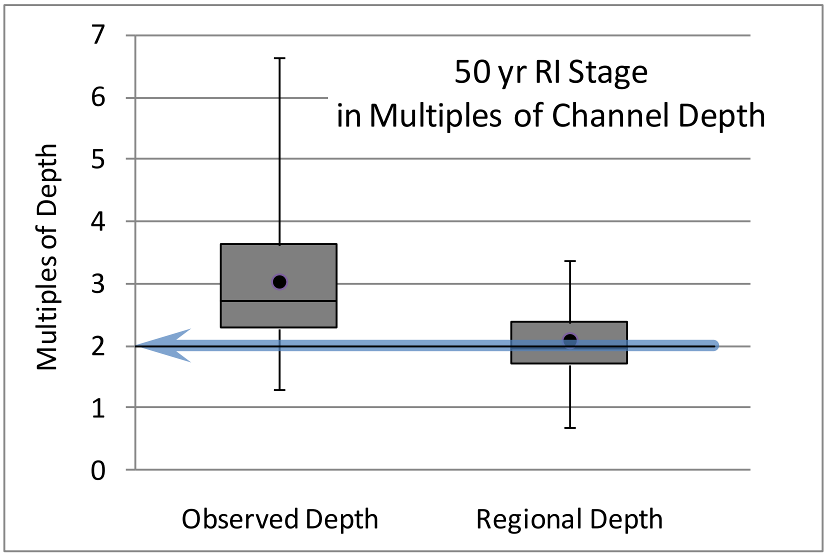

Figure 13 The 50 yr RI flood stage estimated for 54 stream reaches is shown as multiples of two depth values, observed and estimated from a regional curve. The mean is shown as a dot, the bars represent the inter-quartile range and the whiskers show the maximum and minimum. The multiple of two, highlighted, is used in the definition of entrenchment ratio for its correlation with flood events of this magnitude.

Equation 5 is Dunne and Leopold's (1978) Eastern U.S. regional curve for mean bankfull depth converted to maximum bankfull depth. It has been found to work reasonably well in describing streams in Ohio (Ohio EPA 2009c). Flood stages were calculated again this time as two times the regional curve maximum channel depth. As Figure 13 shows, two times the regional curve depth was much better than the measured channel depth for predicting a stage associated with large floods. The 50 yr RI peak discharge stage estimated in the assessed streams averaged 2.1 times the regional curve depth with a standard deviation of 0.5. Further analysis presented in this report uses both measured values and regional values for normalization.

$$d_{max} = 2.2(DA)^{0.24} \qquad \text{(Eq. 5)}$$

Regional curve maximum channel depth where: d_{max} = maximum channel depth measured in a riffle or run, and DA = drainage area (mi^2).

Entrenchment Ratio - The entrenchment ratio, Equation 6, was developed as a rapid field technique to quantify entrenchment and geomorphic stability. However, it has also been used to benefit water quality. Entrenchment ratios have frequently been specified in Section 401 water quality certifications as a performance standard.

$$ER = \frac{W_{FPA}}{W_{BkF}} \qquad \text{(Eq. 6)}$$

Entrenchment ratio where: ER = entrenchment ratio, W_{FPA} = width of floodprone area at a stage 2 times the maximum channel depth, and W_{BkF} = bankfull channel width.

Entrenchment ratios are a primary delineative criterion of the Rosgen Classification of Natural Rivers. Channels are defined as entrenched, moderately entrenched and slightly entrenched, by entrenchment ratios less than 1.4, 1.4 to 2.2 and greater than 2.2, respectively (Rosgen 1994). This suggests that for Ohio streams, the vast majority of which have slopes less than 2%, one would expect stable functioning streams to have entrenchment ratios above the 2.2 threshold. Streams with values below 2.2 typically are associated with instability and poor habitat (Rosgen 1996). While entrenchment ratios of natural streams vary considerably, they are generally much higher than the 2.2 threshold. For example, the average entrenchment ratio Rosgen (1996) presented for the natural stream Type C4 was 5 and while the Type E4 was 57. Both are common channel types in Ohio. The target floodprone width (Equation 4) corresponds to an entrenchment ratio of about 10.

Only two of the sites assessed had slopes steep enough to expect channels to be moderately entrenched naturally, which they were. Meadowlands Town Center had an entrenchment ratio of 1.7 and ODOT SR 37 a value of 1.9. The rest of the sites all had slopes well below the 2% slope threshold where natural streams would be expected to be slightly entrenched, assuming a single thread channel. Of these 52 sites, 46% were more entrenched (smaller entrenchment ratio) than suggested by the classification system. The median entrenchment ratio based on the observed channel depth and width was 2.3 with the inter-quartile range of the sites from 1.7 to 3.6.

Two issues presented themselves when applying entrenchment ratios based on observed values. The first was that not all channels are naturally single thread channels. Channels such as high-energy braded channels, while they have wide flood flows, are still highly entrenched (Rosgen 1996). Similarly, low energy discontinuous or wetland streams may have high entrenchment ratios yet ample flood prone width. The second issue, as discussed above, is that channel dimensions do not always provide a consistent value for normalization. Preferably, the variability of different channel types would not affect the quantification of floodprone width.

To avoid the problems these two issues present, substituting channel dimensions from regional curves for the measured channel dimensions may provide useful units of measure for floodplain connectivity. For the same 52 sites expected to have floodplains and entrenchment ratios >2.2, still 33% were more entrenched than expected for natural streams. The median entrenchment ratio was 2.8 and the inter-quartile range of the sites from 2.0 to 5.9 (Figure 14).

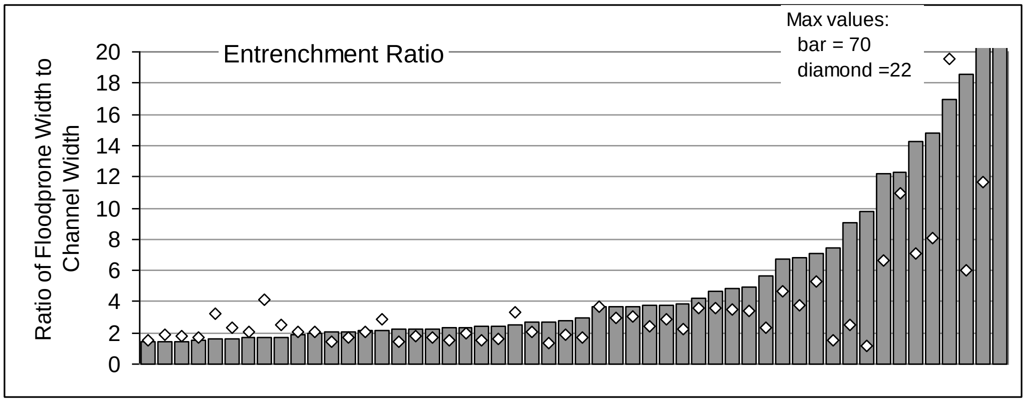

Figure 14 Entrenchment ratio of 52 streams based on regional curve derived channel dimensions shown as bars and observed dimensions shown as diamonds. Correlation coefficient between them is 0.84.

Target Floodplain - A higher resolution assessment of the floodplain may be useful compared to the entrenchment ratio. Surveyed cross sections can reveal floodplain characteristics at lower stages that have a strong influence on ecological services and riparian quality. Figure 15 illustrates a draft method proposed by ODNR and OEPA for assessing floodplain form specifically for its influence on water quality (Ohio EPA 2009c). The highest stage is the same as that used for the entrenchment ratio measured at 2 times the typical regional maximum channel depth. The intermediate stage and lower stage are at 1.5 and 1 times the maximum depth. Because of their ecological importance, the areas saturated or inundated even by shallow backwater are included in the width of each stage. Note this differs from the cross sectional dimensions used for hydraulic analysis which exclude areas not contributing to the flow rate. To account for diminished flooding frequency at higher stages, the area inundated only by the highest stage is multiplied by a weighting factor of 0.4 and the intermediate stage by 0.8. No adjustment is made to the area saturated or inundated at regional bankfull depth.

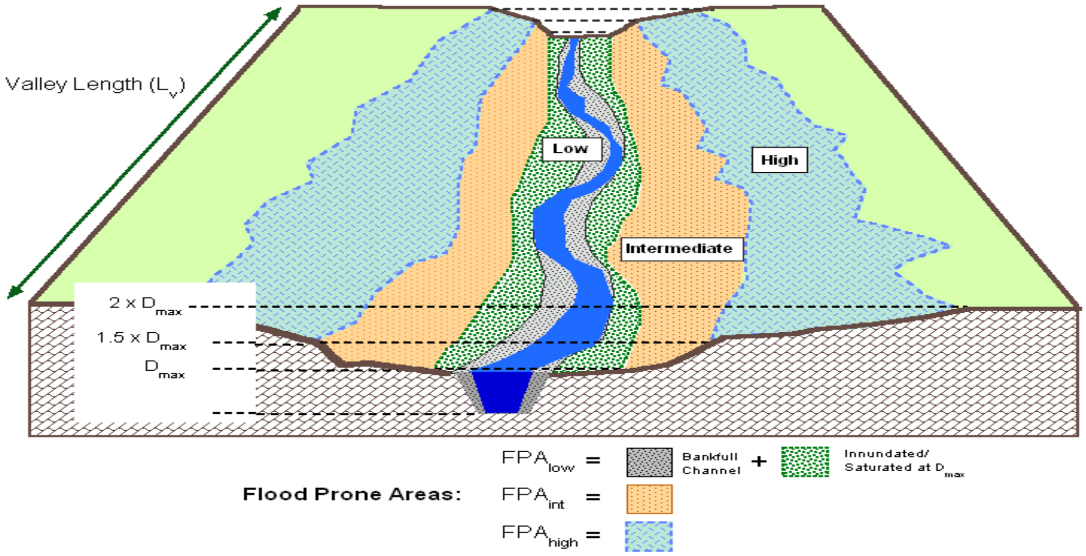

Figure 15 Adjusted Flood Prone Area shown as areas saturated or inundated at three stages with higher areas weighted less.

This measure of floodplain area connectivity can be normalized by making it a percentage of typical natural conditions represented by the regional curve based target floodprone width (Equation 4). For the 52 stream reaches with conditions expected to have floodplains naturally, the median value was 43% of the target width.

Two additional thresholds have been described by ODNR (2006), 50% and 30% of the target width - fifty percent representing the lower end of commonly observed natural floodplain widths and 30% representing the lower end of floodplain widths for which we would reliably expect geomorphic stability and net positive ecological services. Note that 10% of the target is about the width of the channel, indicating high flows are no wider than flows contained in the channel. Eleven of the 52 sites (21%) had floodplains greater than their natural target. Ten sites (19%) were between 50 and 100% of the target and 17 sites (33%) were in the range of 30 to 50% of their target. The remaining 14 sites (27%) had less floodplain width than the minimum defined threshold (Figure 16). The projects ranged from 18% to 530%.

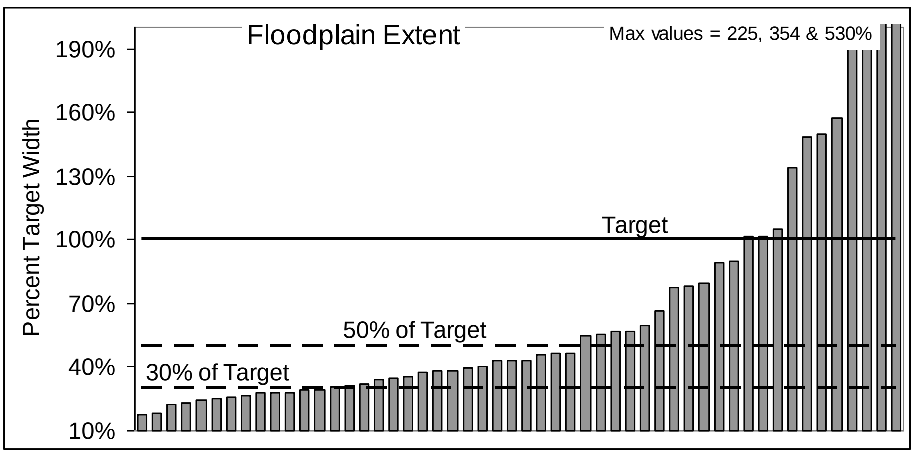

Figure 16 Floodplain extent for stream reaches with slopes less than 2% (n=52), in relation to natural floodplain target width.

Modeled Floodplain Exposure - The two methods above rely on key cross sectional dimensions as indicators of floodplain connectivity. A third more direct model of the flooding process was made to gauge the efficacy of the first two methods as well as to further evaluate this aspect of restoration success.

The model estimates floodplain connectivity in terms of average annual exposure the floodplain has to flooding. To do this, peak flow rates were calculated for each site for the range of recurrence intervals from 0.8 to 100 yr, then the stage and the area inundated at each stage were estimated based on the reach surveys. Multiplying the areas inundated for each recurrence interval by the statistically anticipated number of occurrences for each event over a 100 yr span yields the surface area exposed to flooding per 100 yrs (Figure 17). Finally, dividing by 100 yrs gives the average annual floodplain exposure. The results can be expressed either in units of area (ac) or as a percentage of a benchmark target to facilitate comparative extent of different sized streams. In this case, the benchmark used was target floodplain width (Equation 4, Figure 17) saturated at the 0.8 yr RI event.

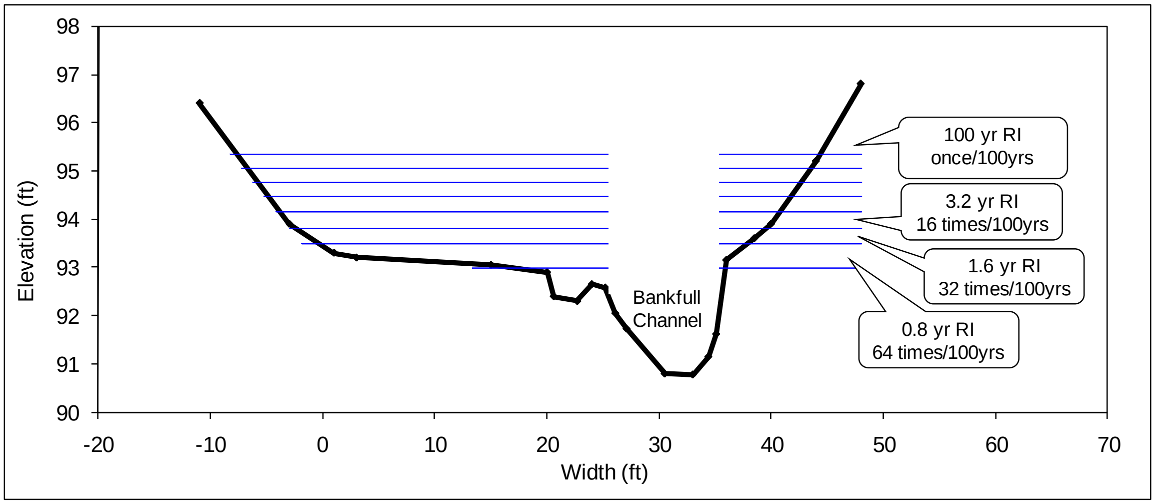

Figure 17 Example of floodplain inundation stages and the associated number of occurrences for each stage of recurrence intervals: 0.8, 1.6, 3.2, 6.4, 12.5, 25, 50, and 100 yr.

Floodplain exposure varied considerably from 1% to 900% of the benchmark natural condition. While seven of the 52 sites were greater than 100% of the target, the median was only 19% and the inter-quartile range of the sites from 9% to 53% of the benchmark target condition (Figure 18).

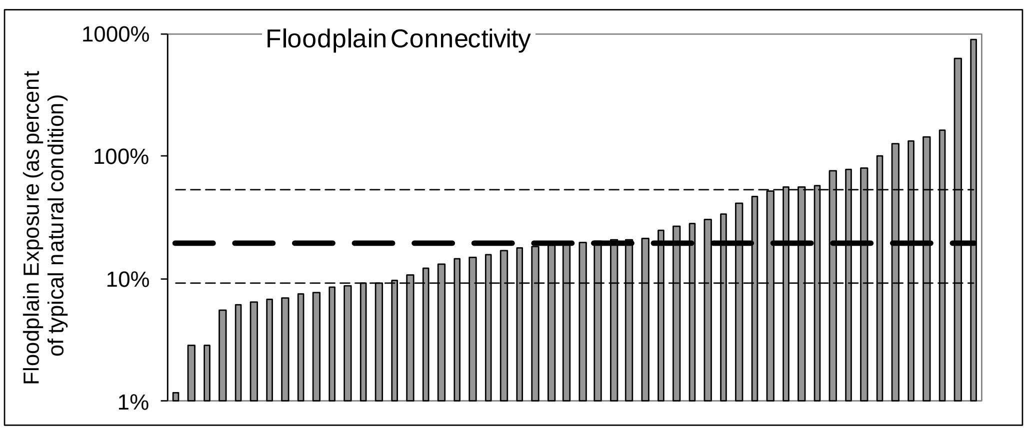

Figure 18 Floodplain connectivity in terms of the area of floodplain-flood exposure relative to a benchmark condition. Floodplain exposure is the cumulative area inundated by 100 yrs of statistically predicted storms. The median value is 19% while the inter-quartile range is 9% to 53% of a standard benchmark natural condition.

Modeling floodplain exposure, while rather laborious, can serve as a useful reference for comparison to other simpler indicators, namely the entrenchment ratio and target floodplain width presented above. The entrenchment ratio based on the observed bankfull channel had the lowest correlation with floodplain connectivity, with a correlation coefficient of 0.37. An entrenchment ratio based on regional channel dimensions had better correlation with floodplain connectivity with a coefficient of 0.59. The target floodplain method based on the weighted widths measured at three stages had the best correlation to floodplain connectivity with a coefficient of 0.88.

Energy in the Channel - The energy driving the formation and maintenance of streams is most often described by the particular conditions when the channel is flowing full. This differs from stream power discussed above which is based on the 2 yr peak discharge and thus independent of the channel size. The bankfull energy is not simply an independent driving variable, but is influenced by the channel form (i.e., size and width).

Bankfull Stream Power - Two approaches were used to describe bankfull stream power, usually simply referred to as stream power. First, it was based on the flow rate of the measured bankfull channel flowing full estimated with the Reference Reach Spreadsheet which utilizes Manning's equation (Mecklenburg and Ward 2005). Second, because of the tremendous variability in channel size and the atypically small channels, bankfull stream power was calculated based on the 0.8 yr RI peak flow rate, commonly associated with bankfull flow, (equivalent to 1.3 yr RI annual peak series). The smaller of the two was bankfull stream power based on the observed channel with a median of 2.3 $lb_f/(s{\cdot}ft)$ and an inter-quartile range of 0.77 to 7.6 $lb_f/(s{\cdot}ft)$. The 0.8 yr RI based bankfull stream power median value was 6.6 $lb_f/(s{\cdot}ft)$ and an inter-quartile range 3.6 to 12.4 $lb_f/(s{\cdot}ft)$. These values are shown in Figure 19 relative to data sets that represent a broad range of typical stream conditions. On reference data set from the Gazetteer of Ohio Streams (ODNR 2001), bankfull stream power was estimated using a USGS empirical bankfull discharge equation (Sherwood and Huitger 2005). This produced a median stream power for Ohio of 67 $lb_f/(s{\cdot}ft)$. The other reference data set in Figure 19 is from Western Germany (Harnischmacher 2007) and has a median bankfull stream power of 58 $lb_f/(s{\cdot}ft)$. The bankfull stream power of the assessed sites, using both approaches, averaged an order of magnitude less than the referenced data sets.

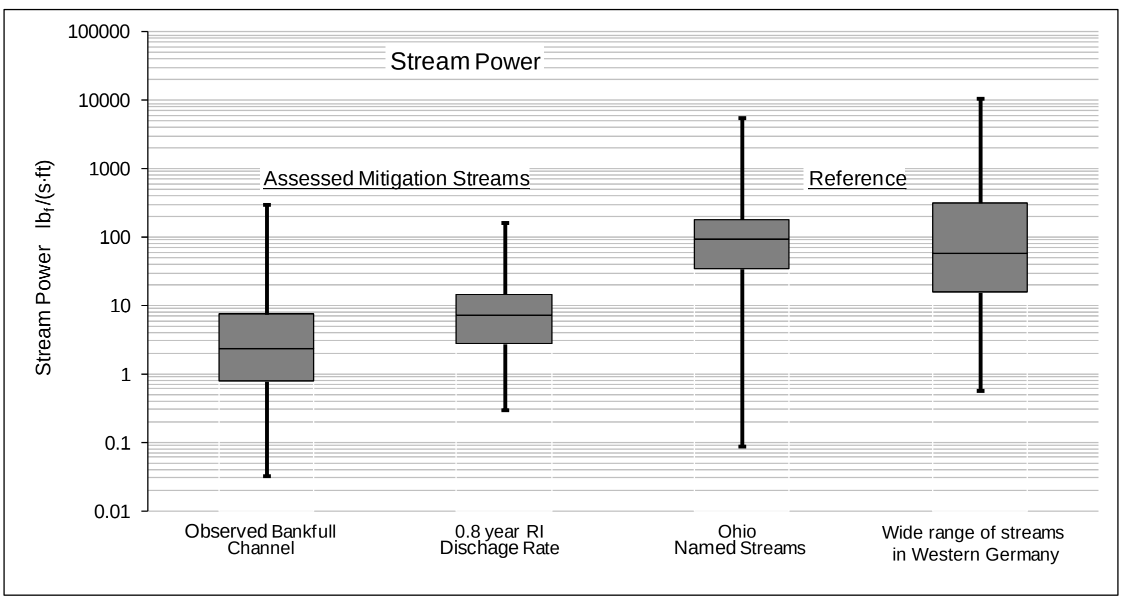

Figure 19 Bankfull stream power of assessed channels is shown based on two methods, the observed bankfull channel and a standard bankfull recurrence interval flow (0.8 yrs). They are shown relative to two reference data sets.

Unit Stream Power - Stream power can be thought of as a description of the stream's longitudinal profile, i.e., the power per unit length along the flow path. Applying the concept of power with the added dimension of cross section apportions stream power across the width of flow and is called unit stream power. Specifically, it is power per unit channel length per unit channel width and calculated as shown by Equation 7. Unit stream power is even more strongly dependent on the local channel form, notably channel size. Relying on channel size still presents challenges as discussed above.

$$\omega = \frac{62.4 \times Q_{BkF} \times S}{W_{BkF}} \qquad \text{(Eq. 7)}$$

Unit stream power where: ω = unit stream power ($lb_f/(s{\cdot}ft^2)$), Q_{BkF} = discharge rate (ft^3/s), S = channel slope (ft/ft), and W_{BkF} = bankfull channel width (ft).

The median bankfull channel unit stream power observed was 0.17 $lb_f/(s{\cdot}ft^2)$ with the inter-quartile range 0.05 to 0.56 $lb_f/(s{\cdot}ft^2)$. Among the sites, values ranged across 3 orders of magnitude, from 0.01 to 21 $lb_f/(s{\cdot}ft^2)$ (Figure 20).

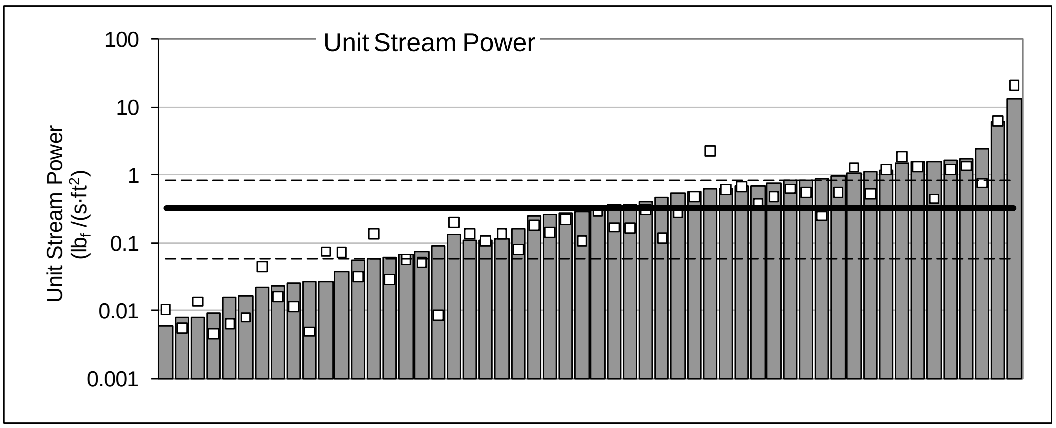

Figure 20 Unit stream power values shown, based on 2-yr peak flow rate and regional channel dimensions shown as columns and based on measured bankfull channel shown as squares.

The unit stream power results are shown relative to other data sets in Figure 21. The often referenced values from Andrew Brookes suggested that streams restored in his study region in England with a unit stream power of 2.4 $lb_f/(s{\cdot}ft^2)$ were stable. Sites with unit stream power greater than 3.4 $lb_f/(s{\cdot}ft^2)$ were prone to failing by erosion whereas channels with unit stream power less than 1 $lb_f/(s{\cdot}ft^2)$ were prone to failing by deposition. Of the 54 channel reaches assessed for this study, 45 had unit stream power less than 1 $lb_f/(s{\cdot}ft^2)$. Another recently published study of low energy systems described as "swamp streams" found unit stream power generally from 0.1 to 0.4 $lb_f/(s{\cdot}ft^2)$ (Nanson 2010), a range around the median of the sites assessed in this study. The range of unit stream power for all streams is suggested by two sources, an analysis of the named steams in the Gazetteer of Ohio Streams (ODNR 2001) and a study in Germany (Harnischmacher 2007), both of which suggest most unit stream power values range between 1 and 10. Another point of reference is a classification system based on unit stream power developed by Nanson and Croke (1992). It describes systems with less than 1 $lb_f/(s{\cdot}ft^2)$ as low energy systems, medium energy channels between one (1) and 20 $lb_f/(s{\cdot}ft^2)$, and high energy systems above 20 $lb_f/(s{\cdot}ft^2)$. Using Nanson and Croke's criteria, one assessed site was high energy, 8 sites fell into the medium range and 45 were low energy.

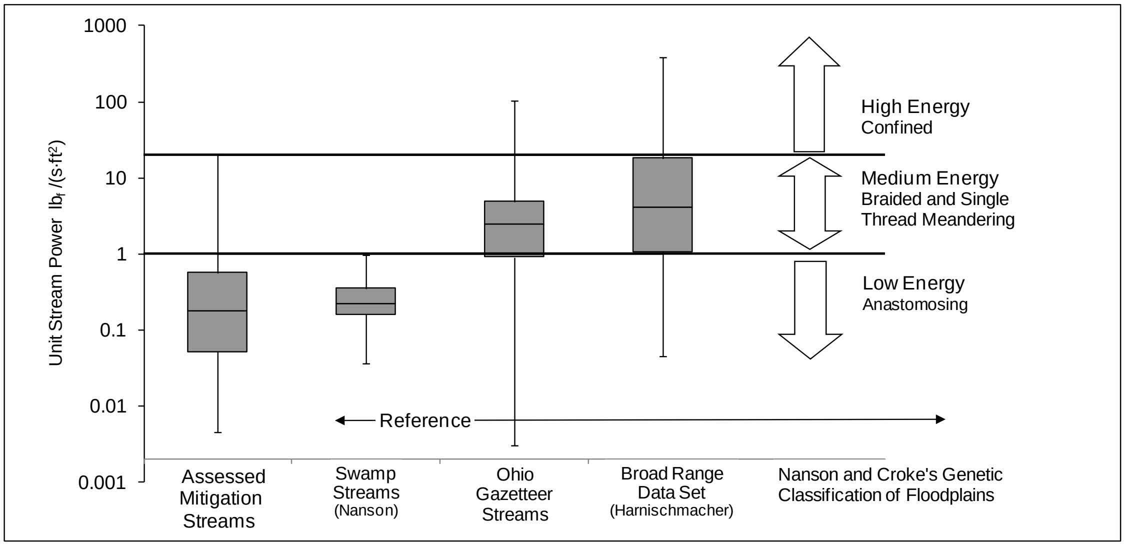

Figure 21 Unit stream power of the assessed streams relative to three reference data sets. The inter-quartile ranges are shown by boxes and whiskers show maximum and minimum values. Lines at 1 and 20 $lb_f/(s{\cdot}ft^2)$ show thresholds of high, medium and low energy proposed by Nanson and Croke (1992).

Sinuosity - One measure of channel planform meandering is sinuosity. It is defined as the ratio of stream length to valley length. For straight channels, the stream length is the same as the valley length and the sinuosity is one. Leopold and Wolman (1992) observed that natural channels are seldom straight. Of 52 channel reaches assessed, 19 had a sinuosity of one, virtually straight with no perceivable meander pattern (two additional reaches were constructed as wetlands and thus not included here). The median sinuosity of all sites was 1.05 and the inter-quartile range was 1 to 1.15 (Figure 22). For reference, channels with sinuosity greater than 1.3 are normally considered meandering and above 3 described as tortuously meandering. Rosgen (1994) described sinuosity as low if less than 1.2, moderate in the range of 1.2 to 1.4 and high if greater than 1.4. The number of channel reaches of low, moderate and high sinuosity observed were 42, 7 and 3 respectively.

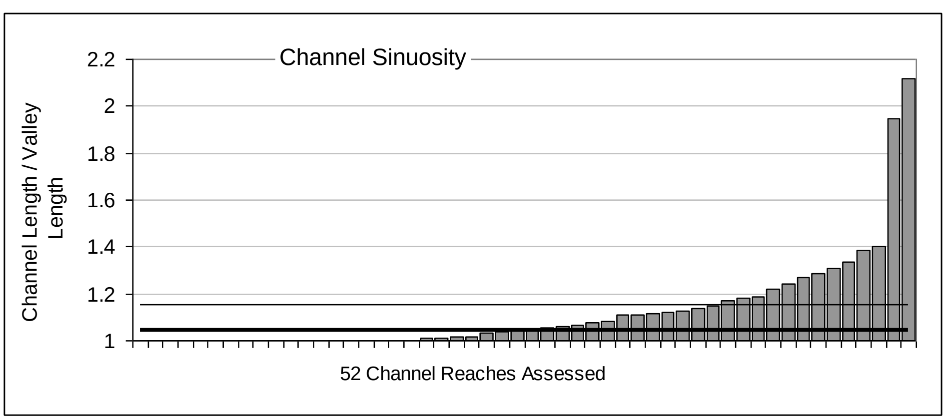

Figure 22 Sinuosity of 52 channel reaches, the first 19 of which have no meandering (sinuosity=1). The median was 1.05, shown as a heavy line. The inter-quartile range was 1.00 and 1.15.

Sinuosity will be limited if the stream restoration is confined to a narrow area. Beltwidth is the lateral extent of a meander pattern and is generally no wider than the streamway or floodprone area. Therefore, the projects with small floodprone areas have the additional drawback of limiting sinuosity.

Using the classic meander pattern geometry proposed by Leopold and Langbein (1966), an area less than about 60% of the natural target floodprone width (Equation 4) begins to limit sinuosity. Figure 23 shows that at 50% of the target streamway, sinuosity is limited to 1.45, whereas streamways of 30% of the target width can accommodate sinuosity no greater than 1.07 (Mecklenburg 2003, Meander Pattern Spreadsheet 4.1). The analysis of the observed floodplain extent showed that 60% of the project sites fell below the 50% target threshold and 27% fell below the 30% target threshold thus limiting the potential for higher sinuosity closer to that typically exhibited by natural channels.

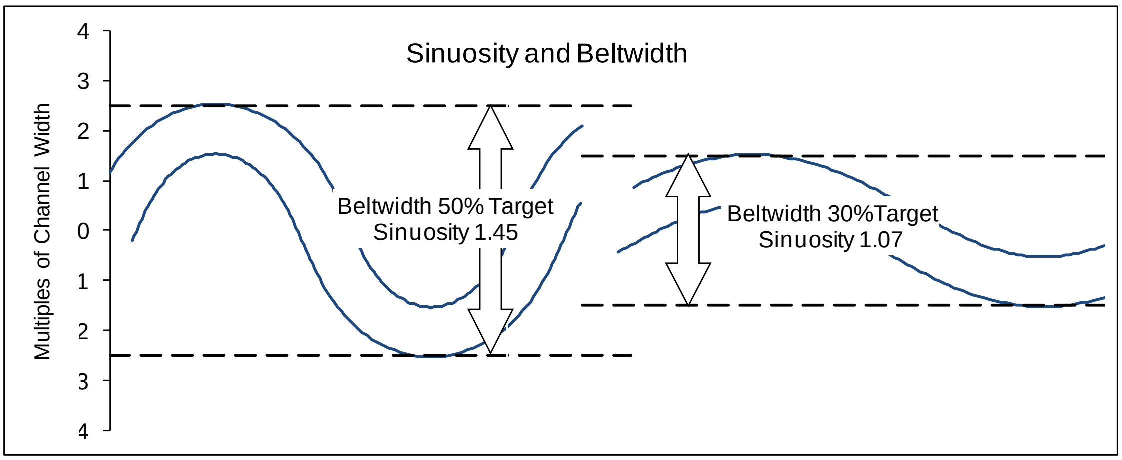

Figure 23 Sinuosity can be limited by the width of the floodprone area. Percentages of the target floodprone width of Equation 4 are shown as dashed lines. Beltwidth is the lateral extent of a meander pattern.

Channel Bed Material – It appeared that about half of the reaches observed included constructed riffles and only a few had continuous rock lining. Ongoing stream processes obscured what the original intent for structures may have been (e.g., engineered riffles or grade control) or whether bed forms had been constructed, formed naturally, or perhaps a combination of the two. The riffle structures observed in their current form, whatever their intended purpose or origin, were assessed for their stability and ecological performance.

Signs of instability, specifically incision, were largely absent. A few channels had evidence of downcutting, but based on a single survey assessment it could not be determined definitively if downcutting had occurred or would continue. Evidence of scour around riffles was common but likely a sign of lateral adjustment rather than imminent vertical instability.

As an indicator of ecological function, the size of existing riffle surface material was compared to the size of riffle material anticipated in a natural stream with the hydraulic conditions of the project site. The threshold of motion theory of channel design describes the bed material at the threshold of motion when the channel is flowing at bankfull and is compared to the dominant size of the measured material (D50 to D84). Observed values were recorded whether the material was placed during construction or deposited over time. Twenty-three of the 54 reaches assessed (43%) had riffle material more than 3 times the size of the material expected in the normal range of mobile riffle material. Of those, eight (15%) were more than 10 times the size of expected natural mobile riffle material (Figure 24).

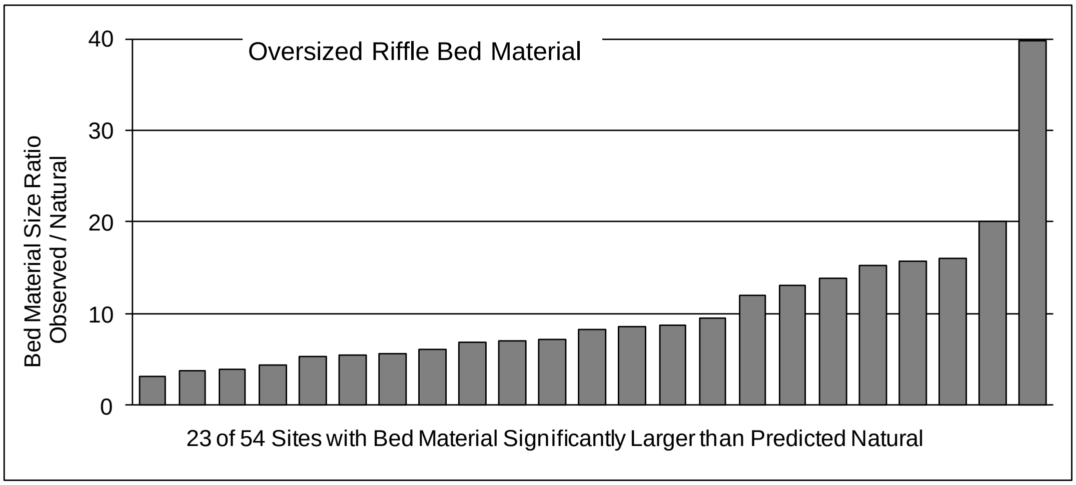

Figure 24 Ratio of the bed material observed to the expected natural mobile riffle material indicates that the placed material predominantly was several times larger than naturally occurring riffle material.

The authors observed anoxic conditions in 19 of 43 sites with constructed riffles similar to the picture of the stained rock from a riffle at Sterling Lakes (Figure 25). It appeared that gravel and cobble were placed, and then post construction fine sediments filled the interstices following construction.

Figure 25 Dark stain on rock from embedded riffle indicating chemical reduction.

In addition to the infilling with fines and presence of anoxic conditions, constructed riffles were frequently colonized by hydrophytic vegetation, predominantly cattails (Figure 26). The vegetative density on the riffles varied from sparse to dense. On some sites, the vegetation was more robust on the riffles than anywhere else on site. At 23 of the 43 sites with constructed riffles, the riffles were colonized with emergent wetland vegetation, described as common on 8, abundant on 7 and dominant on the riffles of the remaining 8 sites.

Figure 26 Riffle colonized by hydrophytic vegetation at the Slane residential site.

Firm substrate was maintained through pools and runs, at least in the thalweg, in 33 of 54 reaches assessed. Muck substrate dominated the remaining 21 sites and, of these, most (14) had constructed riffles. Twenty-two of 54 sites had wetland vegetation colonizing pools and runs. In nine of the 22, the vegetation was thick and robust throughout the reach. However, only two of the nine appeared to have been intentionally designed as wetlands. The other seven appeared to have been constructed as a meandering channel that developed into a narrow meandering wetland (e.g., Figure 27). The vegetation in these seven constructed channels appeared to be more thick and robust than the vegetation on the surrounding floodplains. Vegetation densities were recorded on four of these sites (Table 1).

Figure 27 Constructed meandering channel colonized by vegetation at the Millersburg Walmart site.

Table 1 Vegetation density of four sites examined to illustrate the contrast of vegetation density of some stream channels and floodplains. Sites were selected for dense channel vegetation.

Site Name	Vegetation Density (cm/m^2)	
	Channel	Floodplain
ODOT SR 77	60.5	17.4
Reynoldsburg Kroger	38.4	21.0
Upper Sandusky Reservoir	47.3	4.8
Walmart Millersburg	67.3	14.0
Average	42.7	11.4

Soil Investigations

Seventy-seven soils investigations were performed, 18 of which were reference soils of natural condition. The investigations describe five characteristics of each soil horizon: the horizon thickness, organic matter, permeability, consistence and root density.

Ranking - Two of the five characteristics, organic matter and permeability, were recorded as numeric values with high values assumed to be better than low values. As described in Methods, scales of numeric values were set by the DSWR soil scientists for the other three soil characteristics for which descriptive terms were recorded, for example "B horizon," "friable consistence" or "few roots" again with higher values assigned to physical properties associated with better soil health and greater ecological function. Values for the five characteristics were recorded for each horizon, then weighted by the horizon thickness to give each soil investigation five values, one for each soil characteristic. Ranking the values gave each soil investigation five rankings, one for each soil characteristic.

Overall soil health does not have one measurable indicator. Each of the five characteristics describe somewhat different aspects of soil health. The characteristics are certainly related, but not entirely interdependent. A correlation analysis between each of the characteristics and the sum of all the others showed the correlation was highly significant ($P<<0.001$), for horizon $R^2 = 0.46$, organic matter $R^2=0.48$, permeability $R^2=0.41$ and consistence $R^2=0.54$, whereas there was less correlation between root density and the summed characteristics ($R^2=0.13$, $P=0.0014$).

Overall soil health was designated by a composite of the five soil characteristics observed. Each soil investigation's five individual ranks were averaged. The average rank of its five individual soil characteristics was then ordered from first to last, which was assumed to be best to worst general soil health (Figure 28).

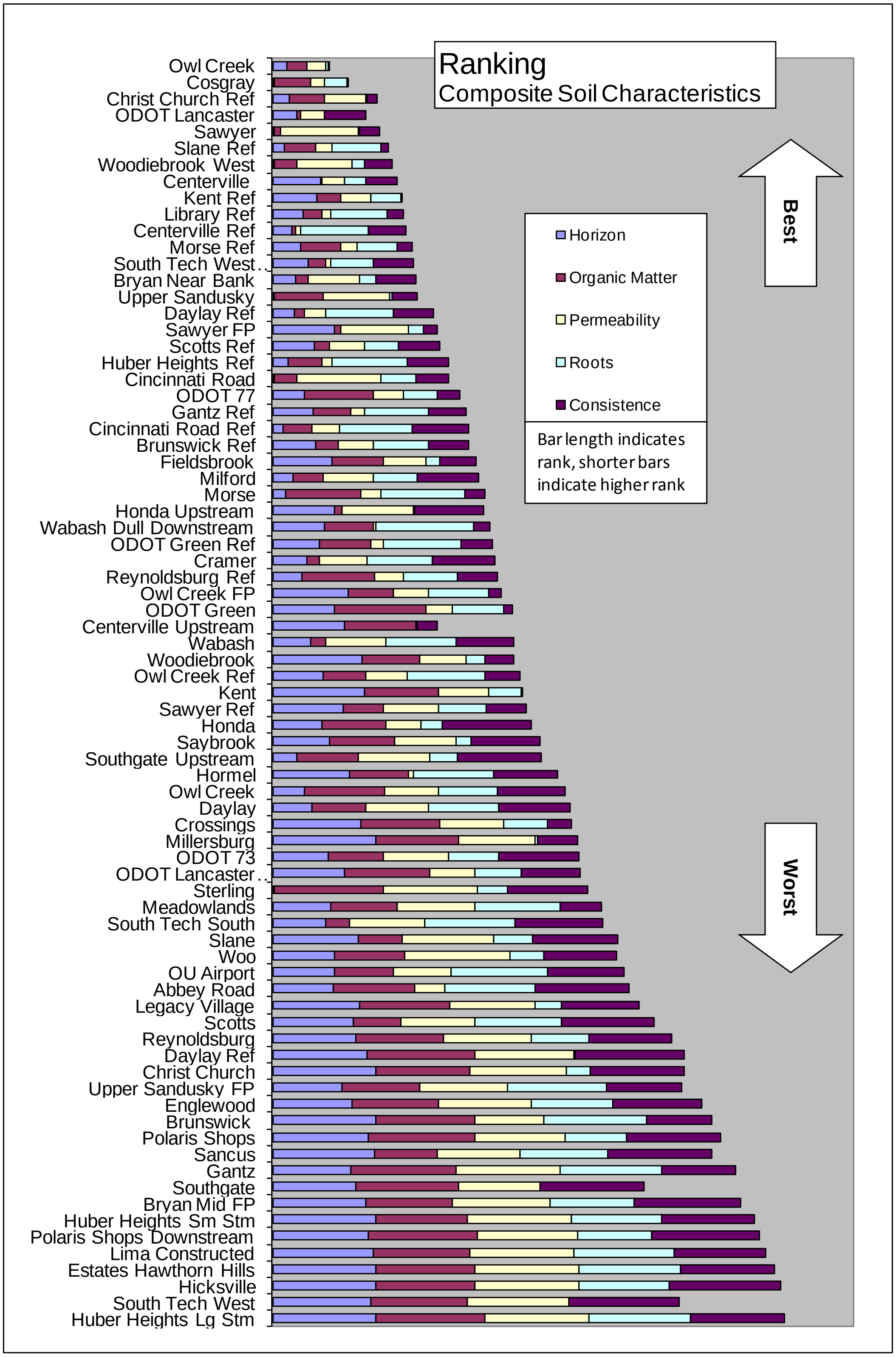

Figure 28 General soil health of sites ordered from top down, best to worst. The top site had the best average of five individual soil characteristics rank. The bars that appear short for their ranking are a result of root density and permeability not recorded in every investigation, but the overall order is still the average rank of available soil characteristics. The list includes natural soil reference condition.

To evaluate the soils of the project sites against natural soil conditions, the top and bottom ranked 22 permitted projects sites were compared to the reference sites. Figure 29 shows the characteristic's average of the permitted project group ranked best, the average of the group ranked worst and the average of the reference sites. Generally, no significant differences were seen in characteristics of natural conditions and the top ranked soils from the project sites while the worst soils consistently had lower values than natural conditions. The most notable difference between the "worst" soils and the "natural" sites was that the lower ranked sites had soils composed of less A horizon and more C horizon (parent material). The lowest ranked sites were also found to have a near absence of consistence qualities of friable, very friable or loose soil.

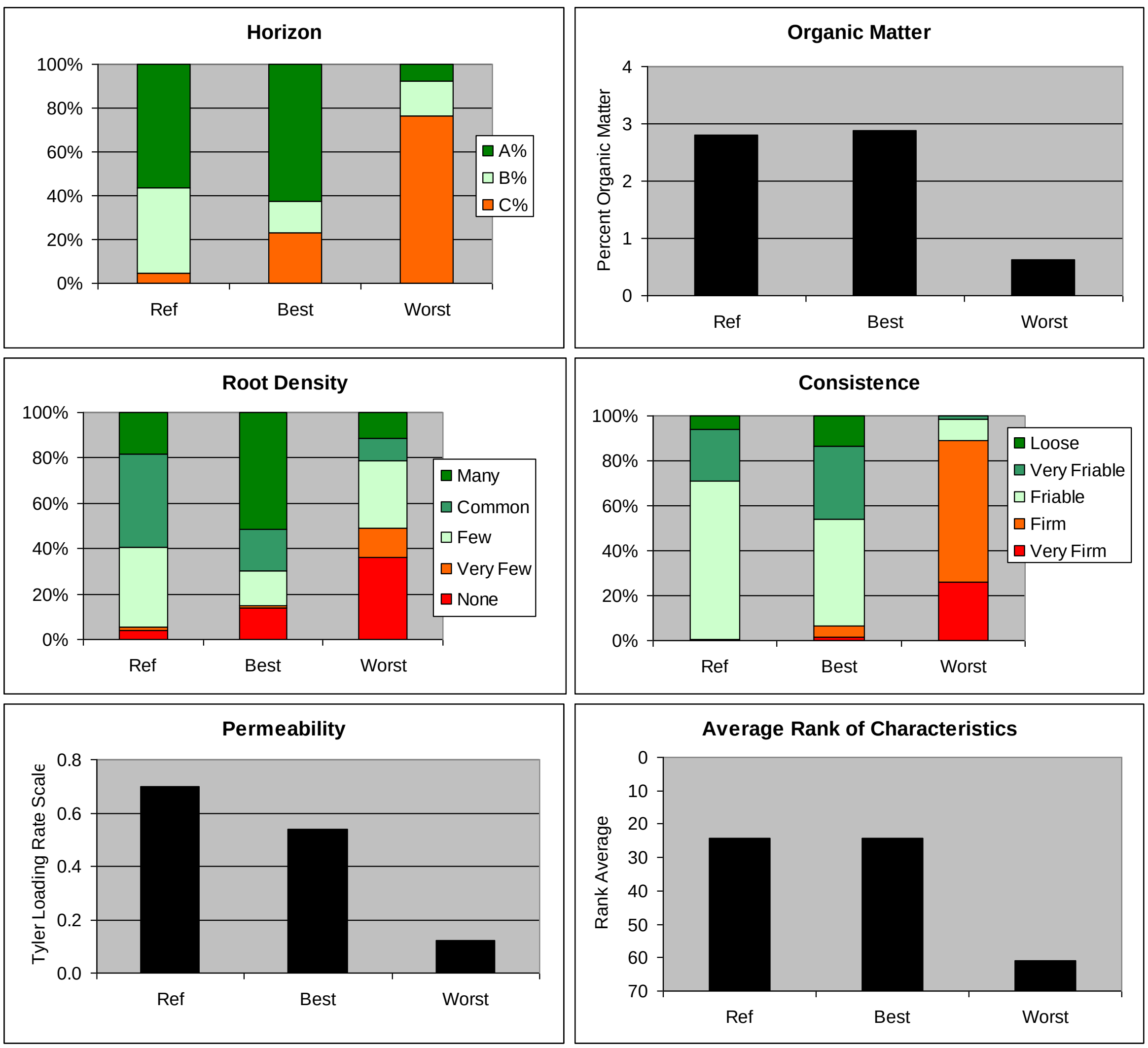

Figure 29 Individual soil characteristics from the 22 stream restoration soil investigations ranked best overall and the 22 ranked worst compared to 18 soil investigations of natural reference sites.

Four permitted projects were excluded from this comparison of the 22 highest and lowest ranked projects. No soils investigation was performed on these four sites because of their high entrenchment and lack of floodplain soil. The soils on each of the four projects sites appeared to poor. If investigations had been performed, they would most likely have been among the 22 ranked lowest. Thus, the disparity between the soil characteristics of the highest and lowest ranked sites is conservative.

Individual soil investigations typically revealed horizons from more than one origin. For example, sediment may have deposited on re-soiled material that had been spread over undisturbed material. So in addition to the comparison of soil characteristics by site, further analysis was conducted comparing soil characteristics by its origin or how the floodplain soil developed, i.e., its morphogenesis. Each soil horizon was identified as:

- recent post-construction deposition (D),
- in-situ or soil that was not moved and was in place prior to construction (S),
- soil placed during construction (C) or
- natural undisturbed alluvial soil used as a reference condition (R).

The soil characteristics were evaluated by the origin and horizon (Figure 30). The A horizons showed the least deviation from natural condition with two notable exceptions, that the organic matter in the constructed soil was somewhat low (mean 16%) and the permeability of the soils identified as in-situ and constructed were -26% and -42% respectively.

The B horizon showed similar deviation, but to a greater degree. The constructed soil organic matter was lowest again (-33%) and the permeability of the in-situ and constructed -23% and -48% respectively. The consistence of the B horizon in the depositional soils was somewhat more friable, while the in-situ and constructed soils were less friable, - 57% and -68% from the friable to firm threshold. No notable deviation was observed in root density except for the depositional B horizon (insignificantly with n=1).

In the C horizon, organic matter was lower than the natural reference condition for all three categories, the depositional being the lowest -72% with in-situ and constructed -53% and -43% respectively. The depositional origin C horizon had the highest permeability, 107% higher than reference C horizons while the in-situ and constructed were lower, -49% and -79% respectively. Consistence had the same pattern with the depositional C horizon all above the friable-firm threshold, 50% more than the reference while the in-situ and constructed were again lower, -52% and -73% respectively. The roots showed the least difference but all having greater root density than the reference C horizon.

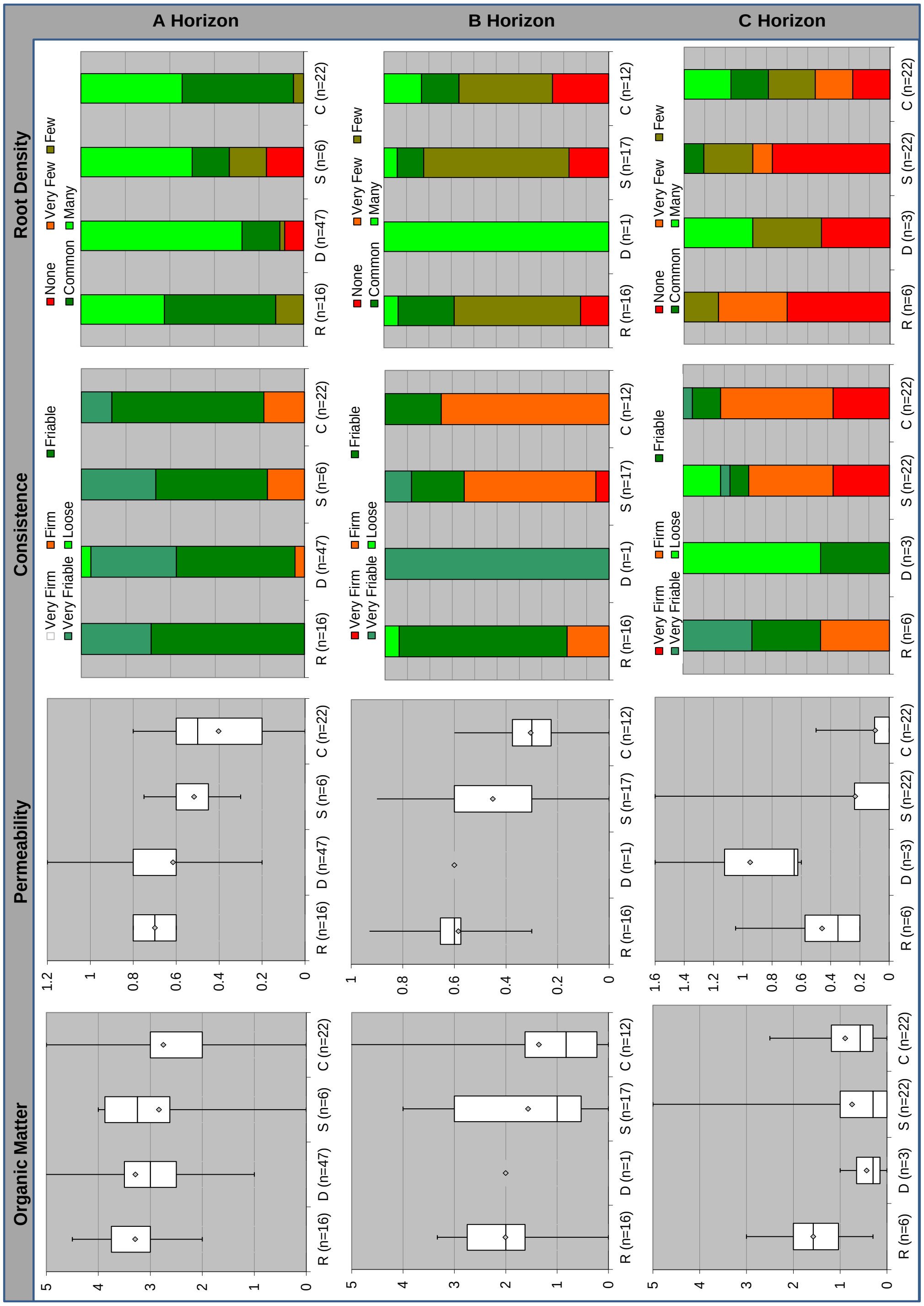

Figure 30 Characteristics of the A, B and C horizons by soil origin; R= reference natural condition, D= deposition post construction, S= in-situ, used in place, C= placed during construction. The mean is plotted as a circle on the bar and whisker quartile plots.

Figure 31 shows how soil quality covaries with factors influenced by soil origin. A correlation analysis was used to test the relationship between the ranking of general soil health and the origin of the soil by horizon. The original ranking was redone excluding the horizon variable from the original five. The correlation of rank on the prevalence of two horizons was highly significant, the depositional A horizon (R^2=0.36, P=0.0002) and the in-situ C horizon (R^2=0.37, P=0.002). Note in Figure 31-A, the linear regression of rank on the log of deposition of A horizon (R^2=0.54) demonstrates the few lowest ranked soils had little to no depositional A horizon. The correlation of rank on the prevalence of constructed A and C horizons were significant (R^2=0.36. P=0.005) and borderline significant (R^2=0.30, P=0.02).

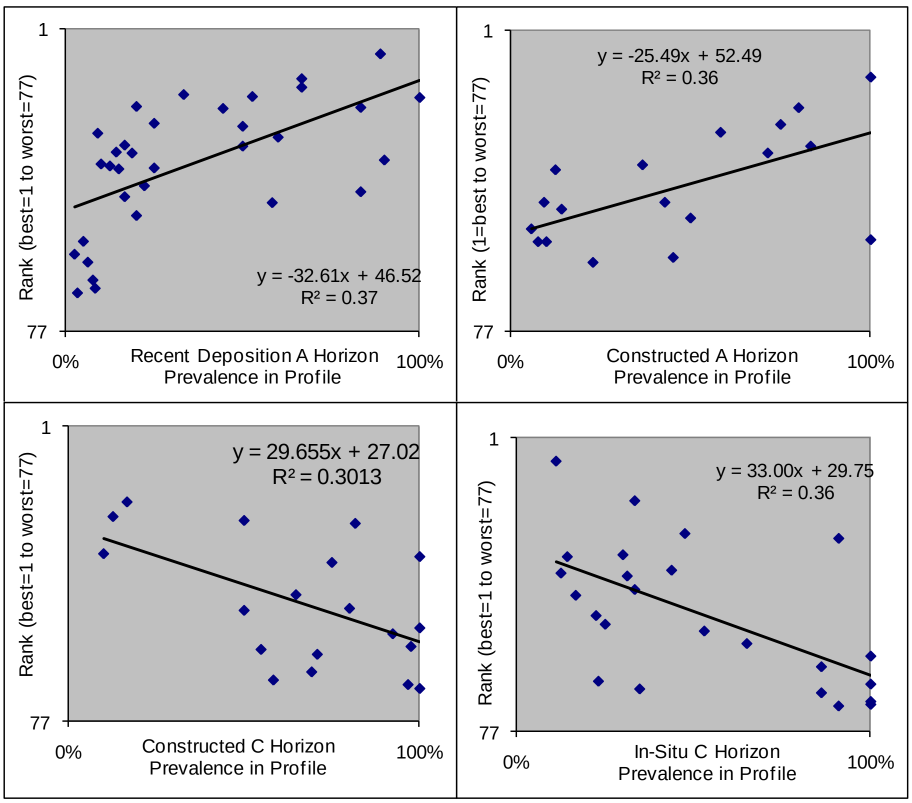

Figure 31 - A, B, C, and D. The prevalence of four of the horizon origins had a noteworthy correlation with the soil investigation ranking from best to worst. For the correlation analysis the soil health rank is calculated without the horizon thickness.

Combinations of characteristics were explored in the interest of providing restoration guidance on conditions to be encouraged or discouraged. By summing the prevalence of various positively correlated soil horizons and subtracting the prevalence of negatively correlated ones, we found two horizon combinations yielding strong correlation with the general soil health ranking based on organic matter, permeability, consistence and root density. Soils with the most A horizon from deposition or in-situ and the least C horizon in-situ or constructed were the best match with the soil health ranking; the correlation was highly significant (R^2=0.69, P<<0.001); the linear regression line is shown in Figure 32-A. The second closest correlation, with nearly identical results, was produced by including the depositional B and C horizons (Figure 32-B).

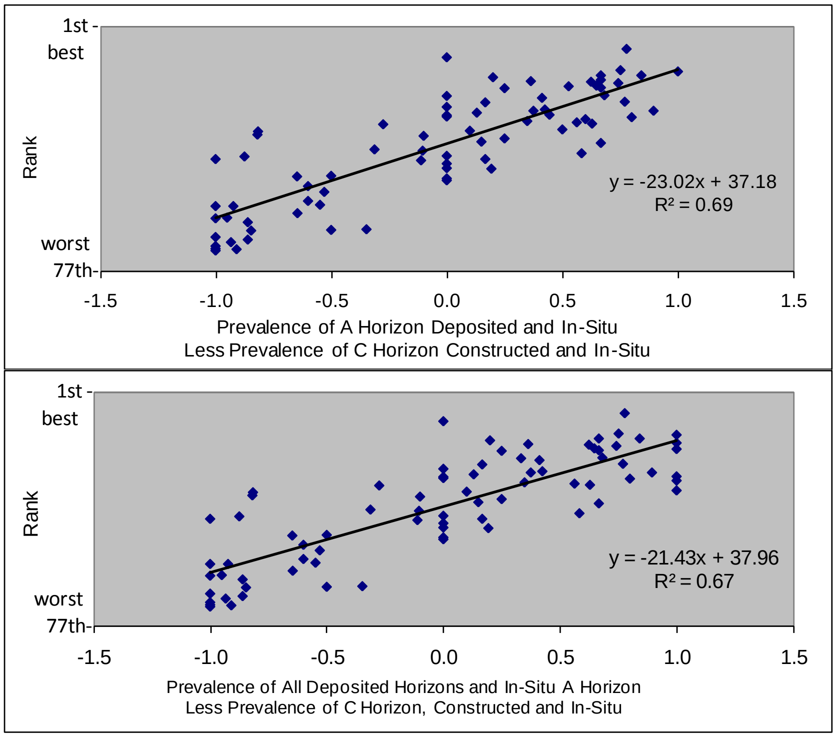

Figure 32-A. Soil profiles with the combination of the most depositional or in-situ A horizon and the least constructed or in-situ C horizon had the closest correlation with general soil health as indicated by organic matter, permeability, consistence and root density. Including all the depositional horizons produced virtually identical results. Figure 32-B includes all depositional A, B and C horizons.

Stream Channel Habitat Assessments

The habitat assessment tool most appropriate for a stream depends mainly on the size of the drainage area (DA). The majority of sites (51 of 54) were small enough (DA<3 mi^2) to be primary headwater habitat (PHWH) and be evaluated with HHEI. Only three sites had sufficient drainage areas (DA>3 mi^2) to make QHEI clearly the appropriate evaluative tool. The drainage area of four sites fell between 1 and 3 mi^2, where in addition to drainage area, the appropriate assessment tool depends on the stream's perceived potential to support warmwater habitat fish and macroinvertebrate communities. Depending on how that is interpreted as many as 11 of the 54 sites might have been evaluated with QHEI.

Stream assessment tools were not necessarily appropriate for all the projects. Ohio EPA's 2009a version of the Primary Headwater Habitat Manual describes a PHWH stream as having a defined bed and bank. Wetland vegetation dominated the bed of seven stream reaches and the banks, if not already obscured by deposition, appeared to be becoming that way. Of these seven, two were constructed as wetlands while the others had been constructed to be streams with a single-thread meandering channel. While 22 sites had wetland vegetation, these seven had continuous robust wetland vegetation and lacked open pools or runs. Thus, the seven stream reaches (13%) were not classified as streams but as wetlands.

Figure 33 shows the distribution of the observed habitats. Most prevalent was Primary Headwater Habitat (PHWH) (44 of 54) and, of those, 27 were Modified Class II, 15 were PHWH with potential for modified Class III biology, and 2 were Class III PHWH. The seven reaches that classified as wetlands were all Category 2 wetlands based on the Ohio Rapid Assessment Ranking. The three largest sites evaluated with QHEI were all Warmwater Habitat. If the intermediate size sites were included there would be a total of four classified as Warmwater Habitat, two Modified Warmwater Habitat and one Exceptional Warmwater Habitat.

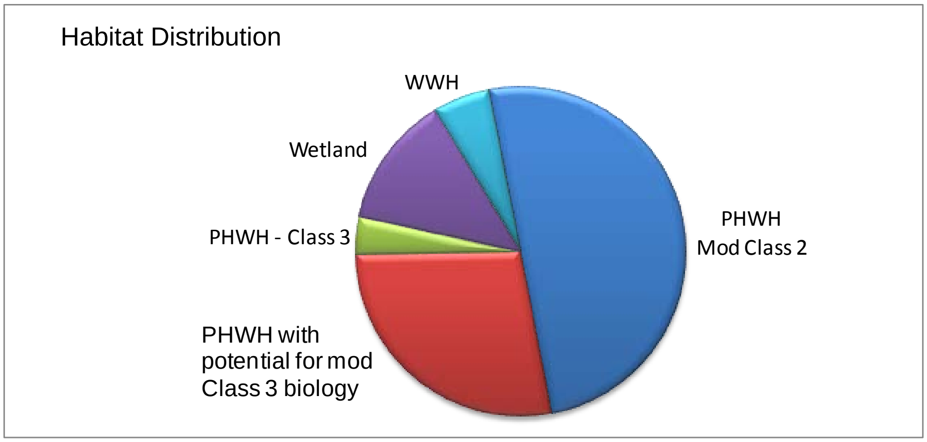

Figure 33 Habitat Types of 54 stream reaches. Primary Headwater Habitat (PHWH) was most prevalent (44 sites), of which 27 were Modified Class 2, 15 PHWH with potential for modified Class 3 biology and two Class 3. Three were Warmwater Habitat (WWH) and seven were Category 2 wetlands.

To analyze and compare the habitat characteristics of all the sites, an HHEI was performed on each site including the three reaches with drainage areas larger than 3 mi^2 and the seven more appropriately classified as wetlands. Figure 34 shows the distribution of HHEI scores from a low of 31 to a high of 86. The median of all reaches was a score of 62 and the inter-quartile range was 53 to 75. The QHEI scores are also shown in Figure 34 for streams with drainage areas greater than 1 mi^2. No significant correlation between QHEI and HHEI was evident (R^2=0.14, P=0.1).

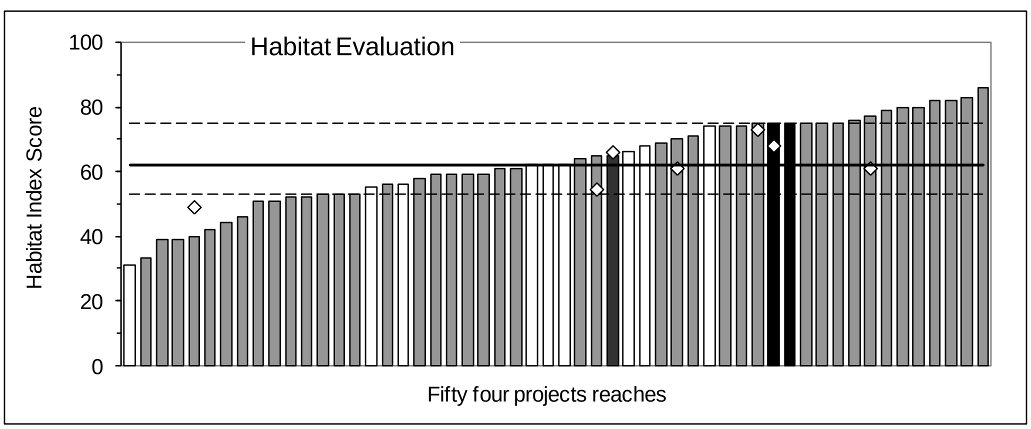

Figure 34 HHEI scores are shown by column height for all fifty-four stream reaches assessed. Channels for which HHEI does not strictly apply are shown in light and dark columns, light for no defined bed and banks and dark for drainage areas greater than 3.1 mi^2. The median (62), and the inter-quartile range (53 to 75), are shown as horizontal solid and dashed lines. QHEI scores are shown as diamonds.

To explore the extent that the habitat index was related to other stream characteristics, a correlation analysis was done between HHEI and virtually all other variables observed or developed from analysis.

HHEI dependent variables are substrate, depth and width. Of these, substrate correlated strongest with the overall HHEI score (R^2=0.6, p<<.001), whereas pool depth and bankfull width both exhibited more scatter (R^2=0.2, p<0.001). Most other variables showing correlation with the HHEI were themselves functions of substrate, depth and width; for example riffle surface D84, regional depth, and shear stress.

Functions other than habitat are associated with driving variables that are not directly a part of HHEI. Correlation analysis of HHEI on variables quantifying vegetation, floodplain connectivity and riparian soil health yielded statistical significance only for variables associated with in-channel vegetation. The linear regression line (Figure 35-A) shows in-channel vegetation density is significantly negatively correlated with HHEI (R^2=0.2, p=0.0005). A similar correlation was found with other wetland characteristics, lack of open pools and runs and silt/muck substrate. For the channels with the most in-channel vegetation the average HHEI score was 16 points lower than the channels with the least vegetation. The vegetation density on the banks, near channel and floodplain showed no significant correlation with HHEI scores (R^2<<0.1, p>>0.05). A similar lack of significant correlation was observed with floodplain exposure (R^2=0.1, P=0.007) and soil health rank (R^2<<0.1, p>>0.05). The linear regression lines are shown in Figure 35-B and C.

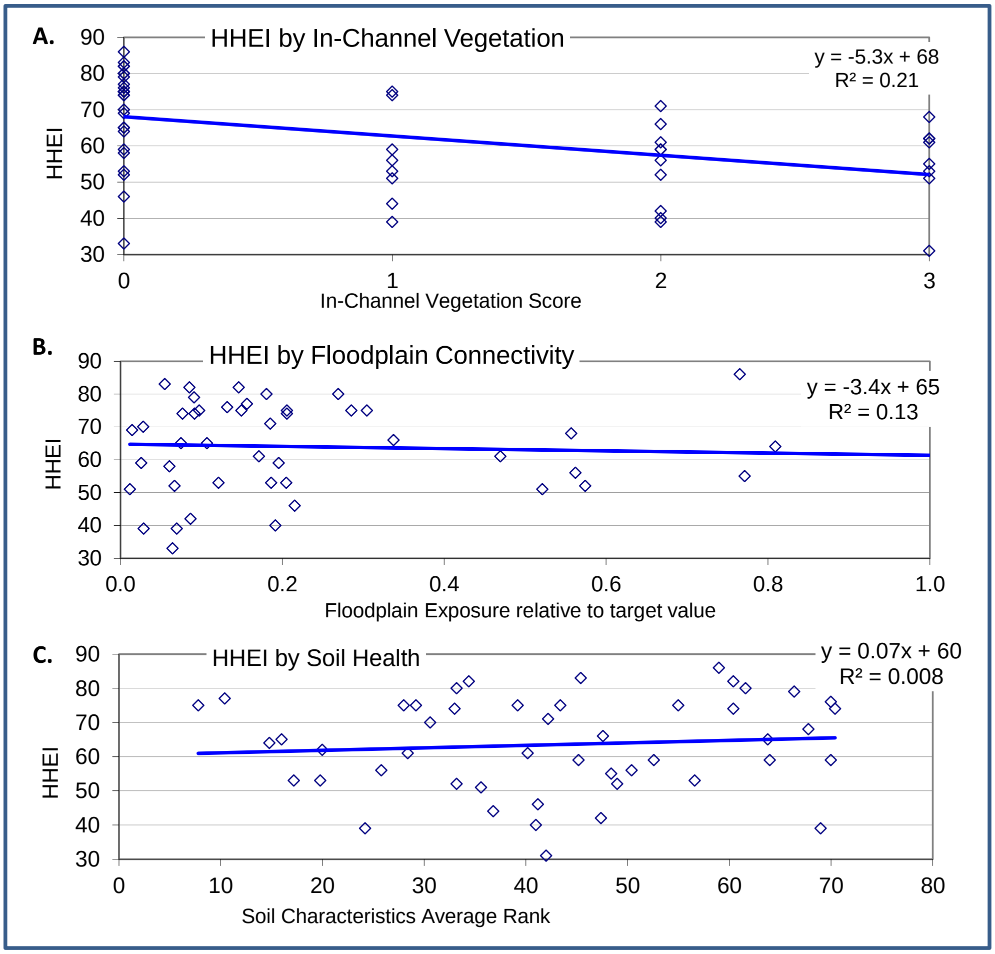

Figure 35-A HHEI was lower on streams with greater in-channel vegetative density. Figure 35-B HHEI was independent of stream's floodplain connectivity. Figure 35-C HHEI was independent of riparian soil health.

HHEI through time - Another variable shown to be significantly correlated with HHEI was the year of construction, or project age when the assessments were completed in 2009. Generally HHEI scores increase with age at a linear rate of 1.7 points per year (Figure 36-A). The positive HHEI trend is not attributed to the pool depth or channel width components, both of which trended slightly lower with age. The increasing trend can be attributed to substrate scores as discussed above. A possible explanation for the trend is that stream processes coarsen the substrate with time. Alternatively, an examination of the energy of stream projects by the year of construction suggests the trend may be a function of stream energy. Few low energy projects were constructed prior to 2002 (Figure 36-B). The projects constructed from 1997 to 2001 had an average stream power of 1.5 $lb_f/(s \cdot ft)$ while those from 2002 to 2006 had an average stream power of only 0.8 $lb_f/(s \cdot ft)$. This may be due in part to changes in Clean Water Act Section 401 and 404 permit requirements and regulations, expanding the permitting scope to smaller and lower gradient streams.

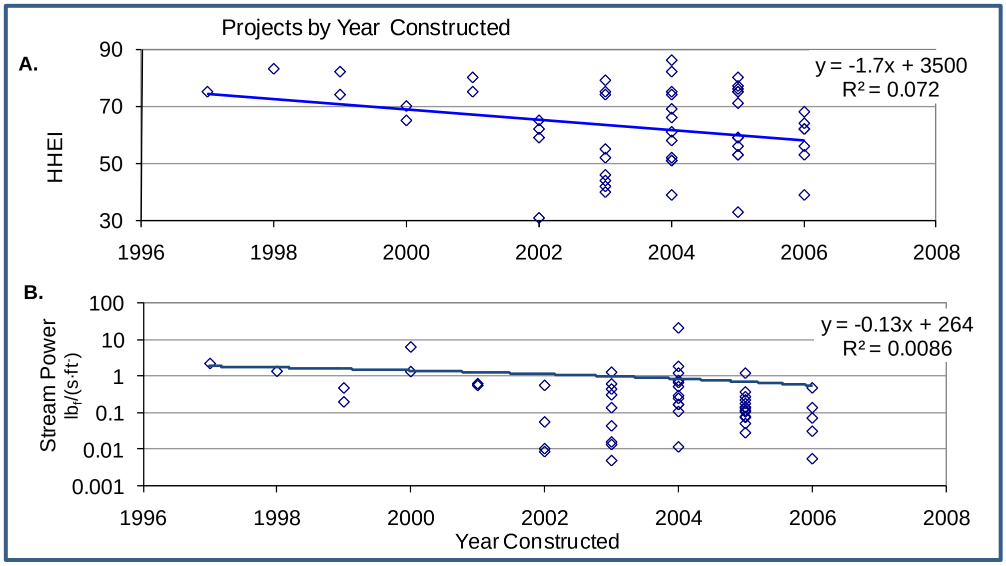

Figure 36-A HHEI scores trend lower for more recent projects. Figure 36-B HHEI corresponds with inclusion of projects on low energy streams.

The variability in the HHEI scores was best explained by stream power. The sites with HHEI less than 60 had a median stream power of 0.08 $lb_f/(s{\cdot}ft)$ while those with a score above 60 had a median stream power of 0.46 $lb_f/(s{\cdot}ft)$, six times more stream power. The correlation of HHEI score and stream power of the 2 yr peak discharge was highly significant (R^2=0.3, P<<.001). The linear regression line is shown in Figure 37.

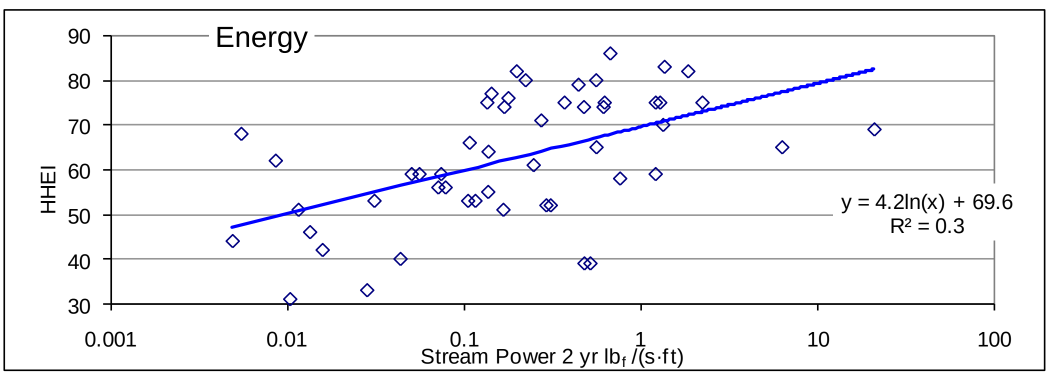

Figure 37 HHEI score has a high correlation with stream power, higher than any other independent variable observed.

Summary and Conclusion

Monitoring and Assessment- Stream restoration efforts around the country have generally been discouraging (Alexander and Allan 2006). However, stream restoration is still an immature science (Tompkins and Kondolf 2007). To increase success, systematic study of stream restoration has been encouraged (Kondolf 1996) along with evaluation and standardization of the assessment methods themselves (Alexander and Allan 2006). The assessment method challenge is complicated by the different meanings of “assessment” at different stages of restoration projects. For example, initial assessment for planning, design and design review is not the same as assessment of post construction performance and ecological response. Different restoration goals exist and even what is meant by “restoration” is debated (Shields et al 2003).

Restoration assessment in this study was based on ecological integrity (Karr and Dudley 1981), Ohio’s legal foundation to water quality law. A conceptual framework of ecological integrity described by Smith (1995) connects broad stream functions to measurable stream characteristics which, as pointed out by Beechie et al (2010), are necessary to evaluate restoration projects. Arguably, the measurable characteristics that are most directly manipulated by restoration work are of primary interest. Thus, this study evaluated characteristics that were 1) necessary conditions for ecological functions, 2) measurable, and 3) products of design.

The types of projects evaluated were limited to those where the primary restoration activity was physical reconfiguration. Projects that were principally planting or preservation, for example, were not included. This study evaluated physical characteristics expected to play a major role in hydrologic, chemical, physical and biological functions. Thus, the morphology of the reconfigured stream was surveyed, analyzed and hydraulics modeled. This included the floodplain form and hydraulics for the key influence these have on ecological functions (Junk, Bayley and Sparks 1989). Similarly, floodplain soils were investigated because the material composition of floodplains influences chemical, hydrologic and biological functions (Van der Putten 2004). Vegetation was evaluated by several methods because of its diverse influence on most functions (Johnson 1995). Finally, habitat was evaluated by applying standard protocols for habitat indices (Ohio EPA 2002), which were further evaluated for their adequacy in measuring ecological functions.

Characteristics of Stream Restoration Projects- The potential of restoration success can be improved by recognizing the broad scale characteristics such as landscape context, process drivers and geomorphic fitness (Beechie et al 2010). Several general site characterizations were evident in the Ohio stream restoration projects assessed.

Fifty-two restored streams completed within the 10 construction seasons from 1997 to 2006 were identified as channel reconfiguration with ecological integrity as a goal. The projects are predominantly streams modified during land development with only three of them initiated specifically for stream restoration.

During those 10 years the total stream length physically reconfigured for restoration was 15 miles, an average rate of 1.5 mi/yr for the entire state. In contrast, the total number of miles of stream channel in the state of Ohio has been estimated between 204,000 and 308,000 miles (Ohio EPA 2010b, Section B). It is not known what portion of the total stream miles are physically degraded, but it is a considerable proportion as indicated by Ohio EPA (2010b), reporting that the leading cause of impairment in over 50% of streams they assessed was channel habitat modification.

With stream restoration driven principally by mitigation, it appears the rate of stream restoration has been spectacularly small in light of the quantity of streams that could presumably benefit ecologically from restoration. On the other hand, depending on projections of urbanization, restoration with land development could presumably present an opportunity for restoring a considerable portion of streams in poor physical condition.

The streams restored tended to the extremes of the ranges exhibited by streams in Ohio in three respects: positions in the watershed, energy, and cross sectional size. First the restored streams tended to be small headwaters. Eighty five percent of the streams assessed were primary headwater habitat, i.e., less than 1 mi^2. While the largest stream's watershed was 12.8 mi^2, all the rest were smaller than 3.5 mi^2. Half of the streams had less than 0.35 mi^2 (220 ac) watersheds and a quarter of them less than 0.16 mi^2 (100 ac). Stream restoration work has been principally at the upstream extent of what are considered headwater streams, on the scale of drainage areas not in square miles but acres - a few hundred down to a few ten's of acres.

Second, the restored streams tended to be low energy for Ohio. Stream characteristics are determined to a large extent by a stream's energy. Channel pattern, floodplain form, and bed material are all influenced by stream energy, commonly expressed as stream power (Knighton 1998). While the restored streams exhibited a broad range relative to the stream power calculated for all named streams in Ohio (ODNR 2001), they were predominantly very low energy. Only three of the restored streams were above the 75th percentile of Ohio named streams. The median value of 67 $lb_f/(s{\cdot}ft)$ for all named streams was five times larger than the median value of the restored streams of 14 $lb_f/(s{\cdot}ft)$. Three-quarters of the restored streams had stream power less than the lowest 20th percentile of Ohio streams.

Another value describing stream energy is unit stream power. This metric also shows a range strongly skewed toward low energy for the restored streams. A classification system proposed by Nanson and Croke (1992) defined streams less than 1 $lb_f/(s{\cdot}ft^2)$ as low energy. Eighty-three percent of the sites assessed had unit stream power less than 1 $lb_f/(s{\cdot}ft^2)$. The familiar single thread meandering channel characteristics associated with medium energy systems are not indicative of low energy systems (Nanson and Croke 1992). The term used by Nanson (2010) to describe streams below 0.4 $lb_f/(s{\cdot}ft^2)$ was "swamp streams". Fifty-five percent of the sites assessed fell below this threshold. This suggests the common archetypal gravel-bed, riffle-pool, single thread meandering channel should not be the design objective for a large portion of Ohio streams that are being restored. Instead the restoration of low energy streams should incorporate more “wetland stream” characteristics.

Finally, bankfull stream channel cross sectional dimensions varied considerably from slightly larger to much smaller than typically reported for naturally forming streams. While the often reported size of natural bankfull channels can be expressed as 70% of the 2 yr peak discharge, only a few of the assessed streams were around the 70% value; six were between 50 and 90% of the 2 yr peak discharge. Many more were much smaller. Half of the restored stream channels corresponded with flows from 25% to as little as 2% of the 2 yr peak discharge. However these observations were consistent with what others have reported for streams in similar settings ; in small headwaters (Richards 1982); in wetland streams (Jurmu and Andrle 1997); and in channels self-formed in over-wide drainage ditches (Landwehr and Rhoads 2003).

Additionally, the prevalence of atypically small channel dimensions could be due in part to the project’s age and stage of succession. Several projects were designed to utilize succession, but it was apparent from recent deposition that several projects with constructed channel dimensions likewise had self-adjusted to a smaller cross section. It is speculated that over time floodplain deposition and shading out of early successional herbaceous vegetation will cause some increase in channel size.

The Division of Soil and Water Resources recommends that stream restoration design and regulatory assessment accommodate the range of stream characteristics found in Ohio, with particular emphasis on streams geomorphic fit to small headwaters and low energy landscapes. These include streams with more wetland characteristics, atypically small cross sectional size and streams that have no defined bed and bank.

Floodplain Connectivity – The form of floodplains governs hydraulic processes at high flows, which is key to the productivity of the stream-floodplain system (Junk, Bayley and Sparks 1989) and self-maintenance of a dynamic channel (Palmer 1976) through a huge range of flow conditions (Leopold 1994). Stream form and process are inextricably coupled, and thus direct measurement of stream form provides information about processes that take place, particularly at high flow rates (Leopold and Wolman 1957, Leopold et al 2005). Floodplain connectivity is a critical variable governing ecological functions - chemical, physical and biological. The choices made during restoration determine the amount of floodplain, its height, extent and all the contingent ecological functions, which will exist beyond the foreseeable future (Maas and Brookes 2010, Urban and Rhoads 2003).

Floodplain connectivity of each site was modeled to estimate the interaction of flow with the floodplain surface. The amount of floodplain connectivity of the restored streams was evaluated by comparing their modeled floodplain connectivity to a benchmark “typical natural condition” (ODNR 2006). Floodplain exposure varied considerably from 1% to 900% of each site’s benchmark. While seven of the 52 sites were greater than 100% of their benchmark, half of the streams were less than 19% and a quarter of them less than 9%. Like natural streams, the assessed projects demonstrated a broad range in the degree of connection between channel and riparian area. However, unlike natural streams, the distribution of the assessed streams was shifted far to the entrenched end of the range. Almost as a rule, the floodplains of assessed projects were far smaller than floodplains of natural streams. The projects' created floodplains were both narrow and high, causing interaction with their riparian area to be limited in extent and frequency.

Techniques for quickly assessing floodplain connectivity were also evaluated. The entrenchment ratio as commonly used poorly described the floodplain, due at least in part to the reliance on bankfull channel dimensions. The atypically small and inconsistent dimensions of the bankfull channels made them poor tools for defining floodplain characteristics. A function of drainage area (regional curve) as an alternative to bankfull channel dimensions provided a better prediction of the intended flood stage. Either way, a considerable portion of the restored streams was shown to be so entrenched they fell below the entrenchment threshold for stable channel types. With flood stage as a function of channel dimensions, 46% of the streams were too entrenched to be Type C or Type E channels. With the alternative drainage area based flood stage, 33% were too entrenched.

Another floodplain connectivity technique was evaluated. The target flood prone width based on drainage area was proposed by ODNR and Ohio EPA defining three flood stages – low (occurring several times annually), intermediate, and high (occurring once in decades) (Ohio EPA 2009c). This method and the two entrenchment ratio techniques were evaluated as simple indicators of floodplain connectivity by comparing them to the modeled inundation over time. The commonly used entrenchment ratio based on measured channel dimensions was found to have the weakest correlation to modeled floodplain connectivity (R^2=0.36, $p<<.001$), presumably due to its reliance on the bankfull channel size to determine a standard flood stage. The alternative drainage area based entrenchment ratio was better (R^2=0.58, $p<<.001$), and the target flood prone width method had the best correlation to the modeled floodplain connectivity (R^2=0.88, $p<<.001$).

The Division of Soil and Water Resources recommends that adequate floodplain form be included in the indicators of success for stream restoration projects. Furthermore, the DSWR recommends entrenchment ratios not be the basis for quantifying the adequacy of floodplain form, but a more precise method be used, one sensitive to frequent floods such as the target floodprone width method described above.

Soil – Several characteristics of soil are pivotal variables governing stream and riparian corridor functions. Many of the fluvial chemical and biological processes take place in soil (Wall 2004). Though the importance of quantifying soil health is well recognized in other fields, that does not seem to be the case for stream restoration. Soil is not a common subject in the stream design and restoration literature, and is largely ignored by the restoration industry and in regulations.

Assessment methods specific to riparian soils are largely unavailable, so a weight of evidence approach was employed in this study utilizing standard soil investigation methods. The soil investigation focused on five characteristics of the soil that were both measurable and understood to govern stream ecological functions. The sites were ranked based on the relative quality of each of the characteristics.

While streams that ranked high for soil quality were comparable to reference sites, the characteristics of the lower ranked sites were substantially worse. In the 22 lowest ranked sites, the indicators of organic matter averaged only 23% that of the reference sites, and the indicator of permeability, the Tyler loading rate, averaged only 17% of the rates scored for the reference sites. The soil profiles of the lowest ranked sites were dominated by C horizon (77%), in contrast to high ranked sites and reference sites that were 23% and 8% C horizon respectively. Root densities for the lowest ranking sites were sparse, with 78% having few to no roots compared to the best ranked and reference sites with 30% and 41%, respectively, having few to no roots. The largest difference observed was for soil consistence, with the lowest ranked sites dominated by firm and very firm soil (89%); whereas both the top ranked sites and reference sites were dominated by loose, very friable and friable soil, 93% and 99% respectively.

In addition to the comparison of characteristics among the sites, another comparison was made between three categories of soil origin on the restoration sites – 1) undisturbed in-situ, 2) placed during construction, and 3) deposited post construction – as well as the natural reference soils. Most restoration sites had two, if not all three, origins present. Soils were further broken down by A, B and C horizons, making twelve categories. The number of samples of each origin varied from n=1 to n=47. Depositional B horizon had only one sample. Among the notable observations (Figure 30) were:

- the characteristics of the A horizons decreased slightly in quality consistently from reference to depositional to in-situ to constructed, with the indicator of permeability having the largest drop (57%),
- the characteristics of the B horizons exhibited similar trends but with more variation, particularly consistence, which was predominantly firm in the constructed and in-situ soils,
- the characteristics of the C horizons did not show as clear trends. Depositional C horizon soil was represented at only seven sites, some of which were gravel lenses with high permeability and low organic matter. Constructed and in-situ C horizons had low permeability, low consistence and slightly higher root density than the C horizon from the reference sites.

The twelve possible combinations of the three horizons from the four origins were analyzed for their correlation to the soil's rank for soil quality. Only four of these 12 combinations showed a correlation. While separately the correlation was weak, together the four combinations showed a significant correlation with the ranked soil characteristics (R^2=0.69, P<<0.001). Thus soil quality as demonstrated by a composite ranking of organic matter, permeability, consistence and root density was predicted by the restoration projects with the most depositional and in-situ A horizons, and with the least constructed and in-situ C horizons.

The Division of Soil and Water Resources recommends riparian soil quality be included in the indicators of success for stream restoration projects. One approach is to define threshold values for key characteristics. Indicators of healthy soil and techniques for quantifying it are well established and presumably could be useful in design and regulation. While standard soil investigation field methods were used for this study, other, specific analysis of key characteristics such as organic matter, respiration or permeability could also be used. This study suggests that even the published physical characteristics of mapped soils (NRCS 2009) are predictive of restoration site's riparian soil health.

In lieu of defining thresholds for specific soil characteristics, the DSWR recommends that to improve the quality of riparian soils, the presence of depositional or in-situ A horizons should be promoted and the presence of constructed or in-situ C horizons discouraged. In more practical terms this would include encouraging reconnecting streams to their original intact floodplain, and creating conditions that promote deposition, while discouraging problematic scenarios such as floodplains composed of existing subsoil, inadequate depth of re-soiling material placed over subsoil, or re-soiling subsoil.

Riffle structures –Riffles are naturally one element of complex dynamic channel forms that are maintained as energy and bed load transport oscillate between riffles, pools and bends (Lisle 1979). The periodic mobilization of natural riffle bed material releases accumulated fine material, a rejuvenating process resulting in more uniformly course material absent fines, allowing interstitial flow, important for biota, groundwater connectivity and chemical processes (Rehg et al 2005). Constructed grade control riffles, on the other hand, necessarily are designed to stay put (NRCS 2007a). Ecological impairments caused by immobile substrate were described by Hester and Gooseff (2010), who found hyporheic flow greatly diminished over time due to fine sediment movement into constructed riffles. While that may be a necessary trade off for vertical stability, the riffles assessed by Hester and Gooseff had been placed not as grade control but expressly to improve hyporheic flow.

Vertical stability was evident in the 54 stream reaches assessed with no appreciable incision observed. Forty-three of the reaches had constructed riffles, 23 of which featured riffle surface rock more than three times that expected to be mobile in similar natural streams. Not surprisingly, anoxic conditions were prevalent in 19 of 43 sites with constructed riffles. It appeared that gravel and cobble were placed, and post construction fine sediments filled the interstices. Also, at 23 of the sites with constructed riffles, the riffles were colonized with emergent wetland vegetation, described as common on eight of the sites, abundant on seven and dominant on the remaining eight.

Riffle-pool bed form is common in natural streams but not universal. While prominent in gravel bed streams, little bed form develops in sand or silt systems (Knighton, 1998). On the assessed reaches it appeared that riffle structures were commonly used where they would not naturally form. Nearly a quarter of all the sites were low energy streams with constructed riffles. Frequent muck accumulation in pools and runs suggested that riffles were functioning as drop structures, dissipating energy then not available to maintain the remaining bed form. Recently, after assessing 26 stream restoration projects in North Carolina, Miller and Kochel (2010) argued for less reliance on structural elements in natural channel design and for designs that accommodate adjustment.

The Division of Soil and Water Resources recommends that riffle structures continue to be encouraged where necessary for grade control, and designed appropriately with large stable substrate but with recognition of their limited potential ecological performance. However, riffles perform poorly if imposed in inappropriate hydrogeomorphic settings and should not be encouraged indiscriminately. Where ecological function is the primary objective, DSWR recommends that riffles be assessed for geomorphic fitness, including the size of material used.

Indicators of Aquatic Habitat – Ohio EPA's Division of Surface Water has been a national leader in using biological indicators to assess overall stream ecological integrity (Ohio EPA 2010b). A strong correlation has been established between biota and habitat (Karr and Dudley 1981). Ohio EPA also established indices of habitat quality, the QHEI and HHEI. However, these indices were specifically designed to predict differences in biology in natural streams, not in reconfigured streams (Ohio EPA 2004b). Ohio EPA determined that the HHEI has not proven useful in distinguishing between various levels of channel modification impacts (Ohio EPA 2004b).

Primary headwater habitat was most prevalent for the assessed restored streams, most of which were Modified Class 2 (50%), followed by modified stream channels with Class 3 biological potential (29%). The next most common (13%) were virtually all vegetated with no defined bed and bank, thus defined as Category 2 wetlands. The median HHEI score of all stream reaches was 62, whereas the inter-quartile range was 53 to 75.

The HHEI variables of channel width, depth and substrate size are each explicitly linked with channel size and energy. The correlation of HHEI score and stream power was highly significant (R^2=0.3, P<<.001). Because habitat indices favor larger and higher energy streams, they are problematic indicators of success for small, low energy restored streams. The regulatory use of HHEI appears to have promoted over-sizing pools, substrate and perhaps channel width.

The Division of Soil and Water Resources suggests that habitat characteristics be encouraged toward an optimum, not a maximum, and that these habitat characteristics include substrate size, pool depth and channel width. DSWR suggests that measures of habitat quality include indicators appropriate for low energy streams and wetlands.

Standards and Guidelines – The HHEI data did not reflect the other characteristics of ecological integrity evaluated in the assessed restoration sites. This study showed no significant correlation between HHEI and the suite of characteristics selected for their role in processes and functions integral to stream ecological integrity.

The results of this study suggest some projects achieved higher habitat index scores by artificially deviating from natural conditions. Specifically, bed material size and pool depth indices award progressively higher scores for bigger rock and deeper pools. Material considerably larger than anticipated for natural conditions was observed in almost half of the projects. In addition, higher scores were awarded for oversized pools that will, in theory, eventually aggrade. Observations confirmed this expectation as accumulated muck substrate dominated 21 project sites. These deviations from the anticipated natural condition diminish stream integrity, yet are encouraged by the use of the current habitat index scoring.

The Division of Soil and Water Resources agrees with Ohio EPA (2004b) and recommends HHEI not be used to judge restoration success. Furthermore, the HHEI certainly should not be used as an indicator of overall physical integrity. Perhaps the use of biotic and habitat indicators can best serve for measuring watershed scale long term success of the programs designed to influence reach scale restoration.

Assessing a broad array of stream characteristics is recommended by Kondolf (1996). Streams are the integration of many ecological functions as described by Smith et al (1995), with simple functions nested in broader processes all the way to the most complex, ecological integrity. This study attempted to focus on characteristics within this conceptual framework that connect broad stream functions to measurable stream characteristics. Broad evaluations were made of morphology, soils, vegetation and aquatic habitat. The results varied widely with each of the stream characteristics exhibiting high to low quality; unfortunately the low quality was well represented. This suggests particular design goals or standards for these stream characteristics were not adequately considered in the restoration design.

The DSWR recommends that physical standards be developed for stream restoration. Furthermore, the DSWR recommends that physical standards: target characteristics underpinning stream ecological functions, are products of design decisions, included standards for riparian soils and cross sectional geometry (inclusive of high flow) and fit with inherent site conditions.

This assessment project suggests stream mitigation and restoration work to date has achieved only modest success in terms of restoring ecological integrity. However, much can be learned from this work to improve future stream restoration.

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Appendix

Appendix Table A Project stream information

	Ohio EPA ID	Year Const	Drainage (sq.mi.)	Length (ft)	Slope (%)	Sinuosity	Bankfull Width (ft)	Bankfull Area (ft^2)
Abbey Road	021737	2004	0.066	1324	0.67	1.01	10.5	5.5
Brunswick	021019	2004	0.42	522	1.1	1.08	13.8	14.9
Bryan Near Bank	049995	2006	0.72	846	0.061	1	9.1	8.0
Centerville	042082	2005	0.94	835	0.43	1.1	10.1	3.5
Central Park	037782	2005	0.025	1059	0.15	1	5.3	2.0
Christ Church	021041	2005	0.098	233	0.35	1	7.7	4.2
Cincinnati Road	033937	2004	0.07	348	0.83	1.002	8.3	4.0
Coffman	021554	2004	0.07	651	1.6	1.01	10.5	4.5
Cosgray	None	2005	1.7	838	0.23	1.06	8.9	7.8
Cramer	062750	2000	0.89	1290	0.53	1	12.9	15.5
Crossings	021881	2003	0.42	2133	0.039	1.1	9.6	9.6
Daylay	None	2003	2.43	2976	0.19	1.1	26.5	19.1
Englewood	032959	2004	0.2	1918	0.69	1.2	14.3	11.0
Estates Hawthorn Hills	052228	2006	0.085	724	0.8	1	8.6	6.0
Fieldsbrook	None	2003	3.6	11783	0.44	1.1	30.7	38.1
Gantz	None	2000	2.35	245	1.5	1.05	15.4	26.2
Hicksville	034057	2005	0.6	1138	0.23	1	5.0	4.9
Honda	048384	2004	0.19	1447	0.1	1	7.4	3.4
Hormel	010139	2001	0.28	2407	0.5	1.2	12.5	10.9
Huber Heights Lg Stm	021284	2003	0.28	326	0.53	1.3	13.0	12.6
Huber Heights Sm Stm	021284	2003	0.12	546	1	1.3	8.9	3.1
Kent	034241	1999	0.11	1096	0.24	1	10.7	9.8
Legacy Village	010231	2005	0.28	1500	0.34	1.1	10.7	5.6
Lima Constructed	None	2006	0.09	1234	0.099	1.1	21.1	11.8
Lyra	052467	2004	0.39	555	0.22	1	16.4	18.2
Meadowlands	048444	2005	0.012	635	2.2	1	5.3	2.3
Milford	021287	2004	0.12	969	0.9	1.04	6.8	3.4
Millersburg	010137	2002	0.07	439	0.22	1.05	16.9	5.7
Morse	042125	2005	0.45	622	0.16	1.02	13.3	10.5
ODOT 37	021923	2004	1	273	4	1	14.0	21.9
ODOT 73	042043	2005	0.34	757	0.51	1	17.1	11.1
ODOT 77	033874	2006	0.28	1000	0.31	1.2	15.8	9.8
ODOT Green	062856	1999	1.53	720	0.49	1	25.8	25.5
ODOT Lancaster	062849	2002	3.11	3394	0.26	1.02	20.7	28.0
OU Airport	010401	2003	0.36	1417	0.41	1.4	18.3	14.0
Owl Creek	063040	1997	12.8	1582	0.54	1	33.6	53.2
Polaris Fashion	052466	2001	0.31	2104	0.14	1.1	13.6	6.8
Polaris Shops	034221	2005	0.57	1082	0.27	1.2	11.7	10.4
Reynoldsburg	020976	2005	1.05	870	0.41	1.03	18.2	14.4
Sancus	035822	2004	0.45	428	0.36	1.3	26.4	18.4
Sawyer	None	2006	0.49	1246	0.19	1.08	12.6	9.7
Saybrook	020831	2003	0.21	1049	0.12	1	6.6	1.9
Scotts	NW 27	2005	0.52	2017	0.22	2.1	21.2	16.3
Slane	020633	2004	0.37	2266	0.47	1.2	12.4	6.7
South Tech South	034301	1998	0.59	2137	1	1.3	17.9	18.5
South Tech West	034301	2002	0.45	2124	0.19	1.4	13.7	10.6
Southgate	022300	2005	0.3	3002	0.21	1	7.0	4.4
Sterling	034016	2004	0.18	1441	1.1	1.04	11.9	9.7
Upper Sandusky	010532	2002	0.1	1200	0.23	1.1	19.0	5.5
Wabash	None	2003	0.45	1300	0.3	1	8.8	7.4
Woo	010130	2003	0.18	2120	0.1	1	5.7	4.1
Woodiebrook	062905	2001	0.17	3200	1.4	1.9	9.9	4.1

Appendix Table B Discharge rate and stream power

	Q BkF	BkF RI	Peak Discharge (cfs)			Stream Power $lb_f/(s \cdot ft)$	
	(cfs)	(yrs)	0.8 yr	2 yr	10 yr	Q bkf	Q 2yr
Abbey Road	7.3	0.78	7	15	39	0.21	0.29
Brunswick	37.3	0.54	51	84	186	0.70	1.86
Bryan Near Bank	7.4	0.24	32	60	134	0.03	0.03
Centerville	4.3	0.12	95	173	384	0.09	0.12
Central Park	1.6	0.43	3	7	17	0.03	0.03
Christ Church	3.7	0.39	7	14	30	0.11	0.11
Cincinnati Road	8.3	0.52	13	27	65	0.25	0.52
Coffman	8.1	0.34	16	26	57	0.42	0.76
Cosgray	8.9	0.16	74	129	269	0.11	0.14
Cramer	52.3	0.85	49	91	206	0.37	1.34
Crossings	5.3	0.25	20	34	67	0.02	0.01
Daylay	9.7	0.14	110	199	442	0.08	0.04
Englewood	22.4	0.63	28	53	120	0.32	0.67
Estates Hawthorn Hills	8.2	0.45	15	30	74	0.33	0.48
Fieldsbrook	143.9	0.58	190	349	864	0.33	1.29
Gantz	103.9	0.51	159	293	737	1.26	6.33
Hicksville	6.2	0.23	27	49	107	0.12	0.18
Honda	1.4	0.14	14	27	62	0.03	0.01
Hormel	25.1	0.54	37	71	167	0.26	0.62
Huber Heights Lg Stm	24.2	0.90	21	42	103	0.29	0.62
Huber Heights Sm Stm	6.4	0.46	12	24	63	0.21	0.44
Kent	14.2	0.38	24	38	77	0.13	0.20
Legacy Village	4.0	0.14	45	75	172	0.12	0.08
Lima Constructed	1.9	0.30	6	10	22	0.03	0.01
Lyra	19.9	0.59	27	51	121	0.14	0.17
Meadowlands	4.7	2.13	2	4	12	0.57	1.21
Milford	3.0	0.17	24	39	88	0.29	0.25
Millersburg	1.3	0.14	18	27	56	0.05	0.01
Morse	17.9	0.25	72	119	258	0.07	0.14
ODOT 37	118.7	1.53	66	134	345	3.59	21.08
ODOT 73	14.7	0.30	49	97	239	0.20	0.27
ODOT 77	5.8	0.20	33	53	114	0.12	0.07
ODOT Green	40.2	0.38	88	171	421	0.29	0.48
ODOT Lancaster	71.6	0.40	140	261	602	0.21	0.56
OU Airport	9.8	0.34	25	49	120	0.19	0.14
Owl Creek	223.0	0.39	427	771	1716	0.53	2.24
Polaris Fashion	1.2	0.12	22	43	104	0.05	0.01
Polaris Shops	15.5	0.36	36	69	162	0.13	0.22
Reynoldsburg	26.3	0.37	55	101	227	0.20	0.37
Sancus	19.8	0.53	30	56	131	0.16	0.17
Sawyer	14.6	0.54	21	39	82	0.09	0.14
Saybrook	0.4	0.11	12	22	47	0.02	0.00
Scotts	11.4	0.30	34	65	154	0.11	0.07
Slane	4.5	0.20	29	58	146	0.16	0.11
South Tech South	39.2	0.48	61	110	238	0.61	1.37
South Tech West	6.4	0.15	58	112	267	0.09	0.06
Southgate	2.7	0.19	16	28	56	0.08	0.05
Sterling	21.2	0.43	35	59	134	0.53	1.22
Upper Sandusky	1.1	0.21	6	12	25	0.04	0.01
Wabash	14.5	0.40	27	48	105	0.14	0.31
Woo	1.4	0.17	10	18	38	0.04	0.02
Woodiebrook	6.4	0.41	13	24	57	0.33	0.56

Appendix Table C Floodplain widths

	Dmax			Measure Dmax Based Stages			Regional Based Stages		
	BkF (ft)	Regional (ft)	0.8 RI (ft)	1x (ft)	1.5x (ft)	2x (ft)	1x (ft)	1.5x (ft)	2x (ft)
Abbey Road	0.48	0.86	1.15	10.5	14.9	74.5	5.2	14.9	74.5
Brunswick	0.44	1.78	1.79	13.8	24.2	40.0	10.6	24.2	40.0
Bryan Near Bank	0.12	1.37	2.15	9.1	16.5	21.1	13.0	16.5	21.1
Centerville	0.03	0.63	1.52	10.1	21.1	24.9	14.4	21.1	24.9
Central Park	0.24	0.55	0.91	5.3	6.3	7.3	3.6	6.3	7.3
Christ Church	0.27	0.94	1.26	7.7	17.7	22.3	6.1	17.7	22.3
Cincinnati Road	0.31	0.69	1.16	8.3	10.3	12.3	5.4	10.3	12.3
Coffman	0.31	0.65	1.16	10.5	12.5	14.6	5.4	12.5	14.6
Cosgray	0.07	1.36	2.59	8.9	22.0	29.0	18.0	22.0	29.0
Cramer	0.57	1.79	2.14	12.9	17.5	19.8	14.1	17.5	19.8
Crossings	0.15	1.82	1.79	9.6	13.1	16.4	10.6	13.1	16.4
Daylay	0.05	1.19	2.72	26.5	42.1	54.8	20.6	42.1	54.8
Englewood	0.43	1.53	1.98	14.3	33.8	54.4	8.0	33.8	54.4
Estates Hawthorn Hills	0.27	1.03	1.22	8.6	11.4	16.2	5.8	11.4	16.2
Fieldsbrook	0.41	2.00	2.99	30.7	97.1	111.3	23.9	97.1	111.3
Gantz	0.36	2.80	2.70	15.4	33.3	44.0	20.3	33.3	44.0
Hicksville	0.13	1.15	1.95	5.0	17.3	20.6	12.1	17.3	20.6
Honda	0.05	0.83	1.48	7.4	12.8	15.3	7.8	12.8	15.3
Hormel	0.35	1.25	1.62	12.5	24.8	43.6	9.1	24.8	43.6
Huber Heights Lg Stm	0.57	1.50	1.62	13.0	26.5	60.6	9.1	26.5	60.6
Huber Heights Sm Stm	0.26	0.75	1.32	8.9	12.1	14.9	6.6	12.1	14.9
Kent	0.38	1.77	1.30	10.7	19.4	24.3	6.4	19.4	24.3
Legacy Village	0.05	1.12	2.12	10.7	29.6	38.4	9.1	29.6	38.4
Lima Constructed	0.18	0.95	1.23	21.1	37.2	53.6	5.9	37.2	53.6
Lyra	0.39	1.72	1.76	16.4	20.5	24.6	10.3	20.5	24.6
Meadowlands	1.06	0.60	0.76	5.3	7.0	9.1	2.7	7.0	9.1
Milford	0.08	0.84	1.81	6.8	11.4	14.1	6.6	11.4	14.1
Millersburg	0.05	0.85	1.16	16.9	346.6	373.0	5.4	346.6	373.0
Morse	0.15	1.18	1.82	13.3	36.9	40.2	10.9	36.9	40.2
ODOT 37	0.89	2.80	2.20	14.0	20.4	26.0	14.7	20.4	26.0
ODOT 73	0.15	1.10	1.70	17.1	22.6	28.6	9.8	22.6	28.6
ODOT 77	0.11	1.21	1.62	15.8	130.7	184.3	9.1	130.7	184.3
ODOT Green	0.23	1.86	2.44	25.8	34.7	38.0	17.3	34.7	38.0
ODOT Lancaster	0.27	2.32	2.86	20.7	34.3	43.6	22.6	34.3	43.6
OU Airport	0.20	1.65	1.72	18.3	91.6	121.9	10.0	91.6	121.9
Owl Creek	0.29	2.90	3.90	33.6	600.0	656.9	38.7	600.0	656.9
Polaris Fashion	0.03	0.70	1.16	13.6	39.4	46.2	9.4	39.4	46.2
Polaris Shops	0.23	1.50	1.92	11.7	21.4	43.5	11.9	21.4	43.5
Reynoldsburg	0.26	1.38	2.23	18.2	26.7	35.4	15.0	26.7	35.4
Sancus	0.35	1.15	1.82	26.4	39.4	61.5	10.9	39.4	61.5
Sawyer	0.38	1.06	1.85	12.6	112.6	138.0	11.2	112.6	138.0
Saybrook	0.02	0.63	1.51	6.6	9.3	11.7	8.1	9.3	11.7
Scotts	0.18	1.67	1.88	21.2	75.3	170.1	11.5	75.3	170.1
Slane	0.08	0.73	1.73	12.4	16.9	20.6	10.1	16.9	20.6
South Tech South	0.35	1.65	1.94	17.9	23.7	28.8	12.0	23.7	28.8
South Tech West	0.06	1.57	1.82	13.7	20.0	24.0	10.9	20.0	24.0
Southgate	0.10	0.95	1.65	7.0	19.2	23.0	9.3	19.2	23.0
Sterling	0.36	1.23	1.46	11.9	21.7	28.7	7.7	21.7	28.7
Upper Sandusky	0.10	0.70	1.27	19.0	46.4	113.6	6.1	46.4	113.6
Wabash	0.30	1.28	1.82	8.8	14.7	18.3	10.9	14.7	18.3
Woo	0.08	1.08	1.46	5.7	8.4	10.9	7.7	8.4	10.9
Woodiebrook	0.26	0.92	1.44	9.9	20.7	52.8	7.5	20.7	52.8

Appendix Table D Floodplain connectivity

	Floodprone Area (ac)		Exposure (ac/site/yr)	
	Regional Stage	Target	Existing	Target
Abbey Road	0.83	0.56	33	57
Brunswick	0.23	0.68	6.5	76
Bryan Near Bank	0.19	0.73	10	86
Centerville	0.7	2.5	55	300
Central Park	0.098	0.32	2.2	35
Christ Church	0.13	0.28	6.4	31
Cincinnati Road	0.17	0.39	2.9	42
Coffman	0.085	0.21	1.3	22
Cosgray	0.88	3.2	60	380
Cramer	0.42	2.4	7.9	280
Crossings	0.37	1.2	30	140
Daylay	0.8	2.0	43	220
Englewood	0.73	0.91	73	95
Estates Hawthorn Hills	0.17	0.54	1.7	58
Fieldsbrook	8.0	14	450	1600
Gantz	0.14	0.58	7.3	68
Hicksville	0.28	1.2	19	150
Honda	0.69	0.88	53	100
Hormel	0.58	1.0	24	120
Huber Heights Lg Stm	0.26	0.45	10	50
Huber Heights Sm Stm	0.11	0.3	3	33
Kent	0.053	0.18	2.8	19
Legacy Village	0.82	0.92	59	100
Lima Constructed	0.68	0.67	31	55
Lyra	0.29	1.1	1.4	120
Meadowlands	0.10	0.24	0.63	25
Milford	0.38	1	20	110
Millersburg	1.5	0.29	230	25
Morse	0.36	0.78	27	87
ODOT 37	0.23	1.6	2.6	180
ODOT 73	0.43	0.94	18	99
ODOT 77	1.6	0.81	140	86
ODOT Green	0.62	2.3	19	250
ODOT Lancaster	1.8	6.9	60	800
OU Airport	1.3	1.2	100	130
Owl Creek	12	7.8	1200	910
Polaris Fashion	0.53	0.88	45	96
Polaris Shops	0.34	0.78	16	90
Reynoldsburg	0.55	1.4	16	160
Sancus	0.25	0.37	3.3	36
Sawyer	0.97	0.65	60	74
Saybrook	2.1	0.6	450	71
Scotts	0.74	0.55	58	58
Slane	0.48	0.87	33	98
South Tech South	0.23	0.78	4.7	85
South Tech West	0.4	1.1	160	130
Southgate	0.53	1.6	36	180
Sterling	0.27	0.63	10	68
Upper Sandusky	1.3	0.56	71	50
Wabash	0.76	3.4	27	400
Woo	0.033	0.18	1.8	21
Woodiebrook	0.16	0.20	6.0	22

Appendix Table E Channel and floodplain vegetation and roughness

	Bankfull Stage Channel Roughness	100 year Flood Stage Channel Roughness	Near Channel Roughness		Floodplain Roughness	
Abbey Road	0.08	0.05	0.15	dense brush to grass	0.15	dense brush to grass
Brunswick	0.065	0.07	0.05	light weeds to scattered brush	0.04	light weeds
Bryan Near Bank	0.027	0.027	0.08	robust grasses to robust grasses & cattails	0.035	grasses & weeds
Centerville	0.06	0.04	0.08	robust, annuals & grasses	0.08	robust, annuals & grasses
Central Park	0.04	0.035	0.03	mowed	0.03	mowed
Christ Church	0.065	0.07	0.15	robust, annuals & grasses	0.035	mowed grasses
Cincinnati Road	0.04	0.035	0.035	grasses, mowed occasionally	0.035	grasses, mowed occasionally
Coffman	0.05	0.045	0.035	mowed grass to landscaping	0.035	mowed grass to landscaping
Cosgray	0.055	0.035	0.05	dense brush to grasses to cattails	0.03	annuals
Cramer	0.035	0.03	0.08	medium dense brush	0.08	medium dense brush
Crossings	0.035	0.03	0.08	grasses to rushes to brush	0.03	sparse grasses to weeds
Daylay	0.07	0.05	0.07	robust grasses to annuals	0.07	robust grasses to annuals
Englewood	0.05	0.043	0.09	brush to grass	0.035	grass
Estates Hawthorn Hi	0.08	0.05	0.025	bare	0.025	bare
Fieldsbrook	0.03	0.03	0.06	cattails to phragmites to grasses	0.07	cattails to phragmites to grasses
Gantz	0.056	0.047	0.04	brush to mowed	0.03	mowed
Hicksville	0.049	0.15	0.15	brush to dense trees	0.035	robust grass
Honda	0.055	0.05	0.08	cattails to weeds to willow	0.03	sparse weeds
Hormel	0.04	0.03	0.08	sparse grasses to willow brush & cottonwood	0.06	grass
Huber Heights Lg Str	0.052	0.046	0.05	robust grass & scattered brush	0.06	robust grass & scattered brush
Huber Heights Sm S	0.035	0.035	0.07	grasses & brush	0.04	grasses weeds & scattered brush
Kent	0.057	0.53	0.1	willow thicket	0.04	grasses
Legacy Village	0.07	0.04	0.08	robust grasses to cattails to rushes	0.04	grasses
Lima Constructed	0.2	0.2	0.035	sparse weeds & grasses	0.04	sparse weeds & grasses
Lima Parabolic	0.2	0.2	0.035	sparse weeds & grasses	0.04	sparse weeds & grasses
Lima Self Forming	0.2	0.2	0.035	sparse weeds & grasses	0.04	sparse weeds & grasses
Lyra	0.18	0.15	0.03	grass & weeds	0.03	grass & weeds
Meadowlands	0.05	0.05	0.08	robust grasses & brush	0.08	robust grasses & brush
Milford	0.07	0.06	0.07	robust grasses to cattails	0.04	mowed grass & weeds
Millersburg	0.2	0.2	0.1	robust grass & scattered trees	0.1	robust grass & scattered trees
Morse	0.04	0.04	0.1	grasses & cattails	0.1	grasses & cattails
ODOT 37	0.07	0.05	0.05	boulders & sparse brush	0.05	boulders
ODOT 73	0.06	0.04	0.07	grass to brush	0.035	grass
ODOT 77	0.045	0.05	0.15	robust brush to robust grasses	0.03	sparse grass & weeds
ODOT Green	0.044	0.035	0.08	brush to grasses to woody vegetation	0.05	grasses to brush
ODOT Lancaster	0.027	0.026	0.05	brush to grasses	0.035	grasses
OU Airport	0.15	0.1	0.035	grass weeds	0.035	sparse weeds & grass
Owl Creek	0.035	0.033	0.1	brush to robust grasses	0.035	hay to robust brush
Polaris Fashion	0.2	0.15	0.035	weeds to scattered brush to bare	0.035	grasses weeds to cattails to brush
Polaris Shops	0.045	0.036	0.055	grasses to brush	0.035	grasses & weeds
Reynoldsburg	0.06	0.045	0.05	grasses to sparse brush to sparse grasses	0.05	grasses & weeds
Sancus	0.065	0.05	0.035	sparse weeds to cattails	0.03	mowed grass
Sawyer	0.035	0.035	0.1	robust grasses weeds to cattails to brush	0.1	robust grasses weeds to cattails to brus
Saybrook	0.045	0.045	0.2	robust brush to robust weeds & grass	0.04	weeds to mowed grass
Scotts	0.12	0.1	0.07	robust grass to brush	0.06	robust grass to sparse grass & weeds
Slane	0.15	0.11	0.05	robust grass to brush	0.045	grass
South Tech South	0.05	0.04	0.1	robust cattails to robust brush to weeds	0.035	grass & weeds
South Tech West	0.05	0.035	0.13	robust brush to robust cattails	0.045	weeds & grass
Southgate	0.09	0.09	0.035	grasses & weeds	0.035	grasses & weeds
Sterling	0.065	0.05	0.045	weeds & grass to brush	0.035	weeds & grass
Upper Sandusky	0.150	0.05	0.2	robust cattails to robust grass	0.035	mowed short
Wabash	0.035	0.035	0.09	robust grass	0.035	grass & weeds
Woo	0.1	0.09	0.027	grass weeds mowed	0.027	sparse grass weeds mowed
Woodiebrook	0.045	0.045	0.09	dense weeds & grass to dense brush	0.1	dense weeds & grass to brush

Appendix Table F Riffle surface material

	Particle Size at Threshold of Motion (mm)			Riffle Surface (mm)	
	BkF	Regional Dmean	Q 0.8 yr	D50	D84
Abbey Road	10	15	10	0.062	0.062
Brunswick	36	33	32	110	220
Bryan Near Bank	1.3	1.4	1.6	0.062	0.062
Centerville	4	13	18	11	34
Central Park	1.2	2	2	0.062	150
Christ Church	6	6	6	0.062	0.062
Cincinnati Road	11	18	14	0.062	120
Coffman	18	35	27	59	140
Cosgray	7	8	10	40	150
Cramer	16	17	13	30	76
Crossings	1.0	1.0	1.9	0.062	0.062
Daylay	4	9	9	32	67
Englewood	13	13	23	100	190
Estates Hawthorn Hills	17	18	15	0.062	0.062
Fieldsbrook	15	12	7	21	100
Gantz	62	60	61	58	230
Hicksville	6	8	7	90	110
Honda	1.3	2	3	0.062	60
Hormel	14	17	15	11	26
Huber Heights Lg Stm	14	15	15	56	140
Huber Heights Sm Stm	22	32	26	47	81
Kent	7	5	7	92	290
Legacy Village	4	10	11	0.062	0.062
Lima Constructed	2	2	2	0.062	0.062
Lyra	1.1	8	7	0.062	0.062
Meadowlands	15	15	9	81	140
Milford	15	27	27	0.062	16
Millersburg	2	2	2	0.062	0.062
Morse	5	7	8	15	29
ODOT 37	176	134	154	54	300
ODOT 73	10	16	17	83	120
ODOT 77	6	5	5	0.062	0.062
ODOT Green	15	22	25	49	110
ODOT Lancaster	10	12	13	14	27
OU Airport	4	8	7	0.062	0.062
Owl Creek	31	13	11	29	67
Polaris Fashion	3	3	6	0.062	0.062
Polaris Shops	6	6	7	43	95
Reynoldsburg	8	13	11	46	92
Sancus	8	11	9	130	180
Sawyer	4	5	2	0.062	8.4
Saybrook	0.9	3	2	0.062	0.062
Scotts	4	5	5	0.062	0.062
Slane	11	15	14	100	170
South Tech South	33	37	38	54	91
South Tech West	3	4	8	0.062	0.062
Southgate	4	5	6	0.062	1.7
Sterling	28	28	29	88	160
Upper Sandusky	2	3	3	0.062	0.062
Wabash	7	8	8	0.062	0.062
Woo	2	2	3	0.062	0.062
Woodiebrook	16	27	17	18	130

Appendix Table G Soil characteristics weighted score and functional health ranked best to worst

	Ave Rank	Horizon	Organic Matter	Permeability	Consistence	Root	D/*+I/A-C/C-IC
Owl Creek	7.8	1.78	3.1	0.71	3.00	4.00	0.78
Cosgray	10.4	2.00	2.8	0.75	3.00	3.63	0.00
Christ Church Ref	14.4	1.75	2.8	0.60	2.88	4.00	0.75
Sawyer	14.8	2.00	3.5	0.20	2.75	4.00	1.00
ODOT Lancaster	16.0	1.67	4.3	0.68	2.50	---	0.67
Slane Ref	16.0	1.84	2.8	0.73	2.92	3.27	0.84
Woodiebrook West	16.4	2.00	3.0	0.48	2.60	3.85	0.20
Centerville	17.2	1.33	9.7	0.68	2.58	3.67	1.00
Kent Ref	17.8	1.36	3.0	0.60	3.00	3.59	0.36
Library Ref	18.0	1.62	3.1	0.80	2.81	3.18	0.62
Centerville Ref	18.4	1.74	4.0	0.80	2.50	2.97	0.74
Morse Ref	19.2	1.65	2.6	0.73	2.82	3.47	0.65
South Tech West Downstream	19.4	1.53	3.2	0.80	2.50	3.46	1.00
Bryan Near Bank	19.8	1.67	3.4	0.50	2.50	3.75	0.67
Upper Sandusky	20.0	2.00	2.3	0.35	2.63	4.00	0.25
Daylay Ref	22.2	1.68	3.5	0.71	2.50	3.02	0.68
Sawyer FP	22.6	1.00	3.7	0.33	2.83	3.83	0.33
Scotts Ref	23.0	1.41	3.4	0.60	2.50	3.50	0.41
Cincinnati Road	24.2	2.00	3.0	0.13	2.58	3.50	0.17
Huber Heights Ref	24.2	1.77	2.8	0.78	2.50	2.78	0.77
ODOT 77	25.8	1.58	1.3	0.60	2.71	3.50	0.00
Gantz Ref	26.6	1.42	2.7	0.77	2.50	3.04	0.42
Brunswick Ref	27.0	1.37	3.1	0.60	2.50	3.19	0.37
Cincinnati Road Ref	27.0	1.89	2.9	0.65	2.49	2.91	0.89
Fieldsbrook	28.0	1.13	2.2	0.55	2.55	3.85	0.13
Centerville Upstream	28.3	0.89	1.2	1.11	2.78	---	1.00
Milford	28.4	1.71	2.9	0.51	2.21	3.43	0.00
Honda Upstream	29.0	1.00	3.5	0.30	1.50	4.00	0.00
Morse	29.2	1.80	1.2	0.71	2.75	2.70	0.80
Wabash Dull Downstream	30.0	1.20	2.3	0.91	2.81	2.22	1.00
ODOT Green Ref	30.2	1.35	2.0	0.77	2.59	2.77	0.35
Cramer	30.6	1.56	3.4	0.53	1.91	3.03	0.56
Reynoldsburg Ref	31.0	1.63	1.2	0.65	2.50	3.25	0.63
Owl Creek FP	31.4	0.73	2.3	0.60	2.84	3.07	-0.28
ODOT Green	33.0	1.00	0.5	0.67	2.92	3.25	1.00
Wabash	33.2	1.47	3.4	0.47	2.30	2.97	0.10
Woodiebrook	33.2	0.18	1.8	0.54	2.59	3.72	-0.82
Owl Creek Ref	34.0	1.20	2.4	0.58	2.58	2.77	0.20
Kent	34.4	0.18	1.2	0.50	3.00	3.55	-0.82
Sawyer Ref	35.0	0.90	2.7	0.48	2.50	3.30	-0.10
Honda	35.6	1.25	1.5	0.60	0.63	3.63	0.25
Saybrook	36.8	1.15	1.5	0.45	1.50	3.75	0.15
Southgate Upstream	37.0	1.67	1.7	0.30	0.75	3.60	0.67
Hormel	39.2	0.69	1.7	0.80	1.84	2.72	-0.31
Polaris Fashion	40.2	1.58	1.1	0.49	1.67	3.08	0.58
Daylay	41.0	1.43	1.9	0.43	1.36	2.93	0.00
Crossings	41.2	0.25	1.2	0.42	2.69	3.44	-0.87
Millersburg	42.0	0.00	1.0	0.20	2.50	4.00	-1.00
ODOT 73	42.2	1.17	1.8	0.38	0.83	3.25	0.17
ODOT Lancaster Downstream	42.4	0.89	1.0	0.54	2.22	3.33	-0.11
Sterling	43.4	2.00	0.0	0.05	0.83	3.58	0.00
Meadowlands	45.2	1.14	1.4	0.20	2.50	2.64	0.00
South Tech South	45.4	1.19	3.0	0.23	0.71	2.50	0.19
Woo	47.4	1.00	1.3	0.00	1.25	3.50	-0.50
Slane	47.6	0.45	2.4	0.06	0.73	3.50	-0.65
OU Airport	48.4	1.00	1.8	0.48	1.00	2.25	0.00
Abbey Road	49.0	1.00	1.0	0.60	0.50	2.50	0.00
Legacy Village	50.4	0.40	0.6	0.12	1.00	3.60	-0.60
Scotts	52.6	0.53	2.3	0.28	0.50	2.62	-0.53
Reynoldsburg	55.0	0.50	0.7	0.10	0.80	3.14	-0.60
Upper Sandusky FP	56.4	0.90	1.2	0.09	1.13	1.81	-0.55
Christ Church	56.6	0.00	0.5	0.05	0.50	3.62	-1.00
Englewood Downstream	56.6	0.15	0.1	0.05	0.19	4.00	-0.92
Englewood	59.0	0.58	0.8	0.05	0.63	2.71	-0.65
Brunswick	60.4	0.00	0.3	0.31	1.75	0.00	-1.00
Sancus	60.4	0.05	1.6	0.14	0.40	2.54	-0.95
Polaris Shops	61.6	0.14	0.1	0.08	0.50	3.05	-0.86
Gantz	63.8	0.65	0.2	0.00	1.19	0.00	-0.35
Southgate	64.0	0.50	0.3	0.15	0.38	---	-0.50
Bryan Mid FP	64.4	0.15	0.7	0.05	0.23	2.65	-0.85
Huber Heights Sm Stm	66.4	0.00	0.5	0.00	0.50	2.50	-1.00
Polaris Shops Downstream	67.0	0.14	0.0	0.04	0.21	2.83	-0.86
Lima Constructed	67.8	0.07	0.4	0.03	0.58	0.13	-0.93
Estates Hawthorn Hills	69.0	0.00	0.3	0.00	0.50	0.00	-1.00
Hicksville	70.0	0.00	0.3	0.00	0.00	2.50	-1.00
South Tech West	70.0	0.09	0.4	0.03	0.05	---	-0.91
Huber Heights Lg Stm	70.4	0.00	0.0	0.00	0.50	0.00	-1.00

Appendix Table H Habitat index scores and channel vegetation density. For bankfull and bed vegetation: 0= open pools and runs, 1 = some veg in riffles, pools and runs, 2 = continuous robust vegetation. For riffle vegetation: "---" = no riffles, 0 = riffles with no veg, 1 = riffles with some veg, 2 = riffle.

	HHEI					Channel Bed Characterization				
			Pool	Bankfull						
		Substrat	Depth	Width	QHEI	Vegetation Density			Embed	Silt
	Score	(pts)	(pts)	(pts)	Score	Bankfull	Bed	Riffle	Riffle	Muck
Abbey Road	52	7	25	20	---	2	1	---	---	1
Brunswick	82	32	20	30	---	0	0	1	0	0
Bryan Near Bank	53	8	30	15	---	0	0	2	1	1
Centerville	53	8	25	20	---	1	0	---	---	0
Central Park	33	3	15	15	---	0	1	0	0	0
Christ Church	53	25	20	20	---	3	1	0	0	0
Cincinnati Road	39	4	15	20	---	1	1	1	1	1
Coffman	58	33	0	25	---	0	2	1	1	0
Cosgray	77	32	25	20	61	0	0	0	0	0
Cramer	70	25	20	25	61	0	0	0	0	0
Crossings	46	1	25	20	---	0	1	---	---	1
Daylay	40	10	0	30	49	2	0	3	1	1
Englewood	86	26	30	30	---	0	0	0	1	1
Estates Hawthorn Hills	39	4	15	20	---	2	2	---	---	1
Fieldsbrook	75	25	20	30	73	0	0	0	0	0
Gantz	65	20	15	30	54.5	0	0	0	0	0
Hicksville	76	26	30	20	---	0	0	0	0	0
Honda	51	6	25	20	---	1	1	3	1	1
Hormel	75	15	30	30	---	0	0	1	1	0
Huber Heights Lg Stm	74	24	25	25	---	0	0	0	0	0
Huber Heights Sm Stm	79	24	25	30	---	0	0	1	0	0
Kent	82	32	25	25	---	0	0	0	0	0
Legacy Village	56	16	20	20	---	2	0	1	0	0
Lima Constructed	68	8	30	30	---	3	2	3	1	1
Lima Parabolic	62	7	25	30	---	3	2	3	---	1
Lima Self Forming	62	7	25	30	---	3	2	3	---	1
Lyra	51	1	29	30	---	3	1	2	1	1
Meadowlands	59	24	15	20	---	0	0	0	0	0
Milford	61	16	25	20	---	2	1	---	0	0
Millersburg	31	1	0	30	---	3	2	---	---	1
Morse	75	20	25	30	---	0	0	0	0	0
ODOT 37	69	29	20	30	---	0	0	0	0	0
ODOT 73	71	16	25	30	---	2	1	3	1	1
ODOT 77	56	1	25	30	---	1	1	2	1	0
ODOT Green	74	24	20	30	---	0	0	0	0	0
ODOT Lancaster	65	15	20	30	66	0	0	0	0	0
OU Airport	55	5	20	30	---	3	2	2	1	1
Owl Creek	75	25	20	30	68	0	0	0	0	0
Polaris Fashion	61	1	30	30	---	3	2	---	1	1
Polaris Shops	80	25	30	25	---	0	0	0	1	0
Reynoldsburg	75	25	20	30	---	1	0	2	0	0
Sancus	74	24	20	30	---	1	0	1	0	1
Sawyer	64	14	20	30	---	0	0	---	0	0
Saybrook	44	4	25	15	---	1	0	0	0	0
Scotts	59	4	25	30	---	2	0	3	1	0
Slane	66	11	30	25	---	2	0	3	1	0
South Tech South	83	28	25	30	---	0	0	2	0	0
South Tech West	59	4	30	25	---	1	0	2	1	1
Southgate	59	14	25	20	---	2	1	0	1	1
Sterling	75	25	25	25	---	0	1	1	1	0
Upper Sandusky	62	7	25	30	---	3	2	---	---	1
Wabash	52	7	25	20	---	0	0	---	---	1
Woo	42	7	15	20	---	2	1	---	---	0
Woodiebrook	80	25	30	25	---	0	0	0	0	0